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THESIS

MAP USAGE IN VIRTUAL ENVIRONMENTS

by

Helsin Cevik

September 1998

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1998	Master's Thesis

4. TITLE AND SUBTITLE
MAP USAGE IN VIRTUAL ENVIRONMENTS

5. FUNDING NUMBERS

6. AUTHOR(S)
Cevik, Helsin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

It is neither practical nor efficient to represent virtual maps as we do for paper maps in the real world due to major differences in hardware and software capabilities and requirements. Instead, we can determine the parameters that affect virtual map representation and that help to construct a mental map, and then manipulate these parameters in order to increase the effectiveness of map representation as an aid in performing navigation tasks. The approach taken was first to determine and then investigate the parameters that affect virtual map representation through an experiment designed specifically for this thesis. The experiment examined users of an urban and open ocean virtual environment executing a set of navigation tasks with a virtual map with different orientation schemas. The results of this study showed that, a forward-up map orientation is preferable to a north-up map orientation for egocentric tasks and a north-up map orientation is preferable to a forward-up map orientation for geocentric tasks. Under almost every possible condition, individuals with high spatial abilities will be able to use either a north-up map or a forward-up map better than individuals with low spatial abilities. Furthermore, it was found that these principles apply across types of environment with vastly different spatial characteristics, but sparse environments seem to exhibit less of a performance difference than dense environments.

14. SUBJECT TERMS
Virtual environments, wayfinding, navigation, virtual maps, spatial visualization, spatial orientation, cognitive maps, mental rotation

15. NUMBER OF PAGES
139

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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MAP USAGE IN VIRTUAL ENVIRONMENTS

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requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
September 1998

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ABSTRACT

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ACKNOWLEDGEMENTS

This research is sponsored by The Office of Naval Research, Cognitive and Neural Science and Technology Division. I would like to thank the NPSNET Research Group for their valued assistance and cooperation.

I would also like to thank my thesis advisor Prof. Rudy Darken, thesis co-advisor John Falby for their guidance and attention to detail, which contributed to the overall worth of this work. Thanks also go out to my best friend Ltjg. Mehmet Ayik (Turkish Navy) who gave me his time and knowledge in statistical analysis and Capt. John Lawson (United States Army).

I. INTRODUCTION

A. VIRTUAL MAP UNDERSTANDING

We must all deal with two forms of reality – the one that we think exists and the one that actually does. When our conception of reality deviates too much from the one that is actually out there, we cease to function effectively at whatever we are doing. This is especially true for navigation both in the real world and in virtual worlds. The conceptualizations we form in our minds about the physical shape and content of the real world in which we are operating are the only basis we have for our navigational decisions and actions depending on our navigational task.

In order to navigate and achieve an assigned task in the real world effectively, it is a great advantage to know the area as well as one's own neighborhood. If one has not lived in that area for an extended period of time, the most obvious way to get this advantage is through the use of maps. How can we apply this advantage of maps in the real world to maps in virtual worlds as a factor of assigned navigation task?

There are underlying principles, founded primarily in cognitive psychology, geography, and cartography, which can help us to determine how maps in the real world should be represented to achieve optimal performance on navigational tasks. However, maps in virtual worlds differ significantly from maps in the real world. First of all, the viewpoint location is known at all times. Virtual maps can dynamically show the position of the viewpoint (e.g. the You-Are-Here or YAH position) during navigation rather than only at static locations such as the maps at each floor of shopping malls. The same can be said of dynamic objects in the environment. This trivializes the transformation of positions in the egocentric reference frame (ERF: the perceptual information obtained

from the forward view) to the world reference frame (WRF: the information presented in the map). It does not, however, trivialize the rotations necessary to align the ERF with the WRF. That is why, in the real world, we see people turning maps in different directions while they are driving or walking in an unfamiliar area. This issue will be covered in detail in the section on map orientation effects in virtual environments (See Chapter IV).

There are two other important parameters that affect virtual map representation in virtual worlds, namely, individual differences between people and the spatial characteristics of the virtual environment. The transformation (ERF to WRF and vice versa) may be a trainable skill. While it is not suggested that individuals with low spatial ability can be trained to be comparable to those with high spatial ability, they may be able to raise their general level of performance with repeated exposure to perspective transformation skills or applying them during spatial orientation tests. On the other hand, the type of virtual world that we are dealing with can be encountered as a third parameter concerning virtual map usage in these worlds. Navigating in a sparse virtual world is different from navigating in a dense virtual world. Imagine navigating in open ocean where there are not many objects which can help to establish location and facilitate mental rotation versus navigating in a building where there are many objects which facilitate navigation from a mental rotation point of view.

We need virtual maps in order to navigate in virtual environments and to accomplish tasks effectively just as we need real maps in the real world. However, we need to manipulate the parameters explained above that affect virtual map representation in virtual worlds in order to increase the overall effectiveness of the map as an aid in performing the assigned navigation task.

B. MOTIVATION

Many books about map or map use begin their introduction with a statement suggesting "It should be easier to read a map than to read this book". After all, the old aphorism says that a picture is worth a thousand words. If this is true, then it is natural to ask the question "Why do they need to write books about maps and their usage?". The fact is that maps are not as simple and straightforward as they may seem at first glance. On the contrary, a map of our detailed and complexly interrelated sorroundings tends to be extremely symbolic, mysterious, and deceptive. That does not mean that maps themselves are unclear. But it is the mapped world, not the map, which we are trying to understand [MUEH92]. This is also undoubtedly true for virtual maps in virtual environments. If we are unable to match what we see in the real world (Egocentric Reference Frame (ERF)) with the information presented in the map (World Reference Frame (WRF)), then the map is useless.

What we know about the environment is dependent on the way we think and communicate in general. That is, we do not gain environmental knowledge through mere absorption or "looking-and-knowing" insight. It comes through an active process of information gathering, structuring, and association. This process involves transformations of form and substance, which are bound to influence what we eventually know about our surroundings (Figure 1). Maps are the abstraction of our environment that facilitate this process. They serve as a function to convert reality into a mental image of our environment, more precisely into maps in our minds, known as **cognitive** or **mental maps** (Figure 2). As a matter of fact, these are the ultimate maps, because they are the ones we use to make decisions about the environment. Unfortunately, however, our

mental maps are restricted in scope and often fail. When this happens, we need a real map or a **cartographic map** in order to refresh, correct, or create the mental map in our mind [MUEH92].

This brings us to the goal of this thesis. Can we effectively present virtual maps in such a manner that they can help in the construction of a bridge between the virtual environment and the cognitive map of the user? In order to answer this question, we must first clarify the parameters underlying this representation and then determine how best to

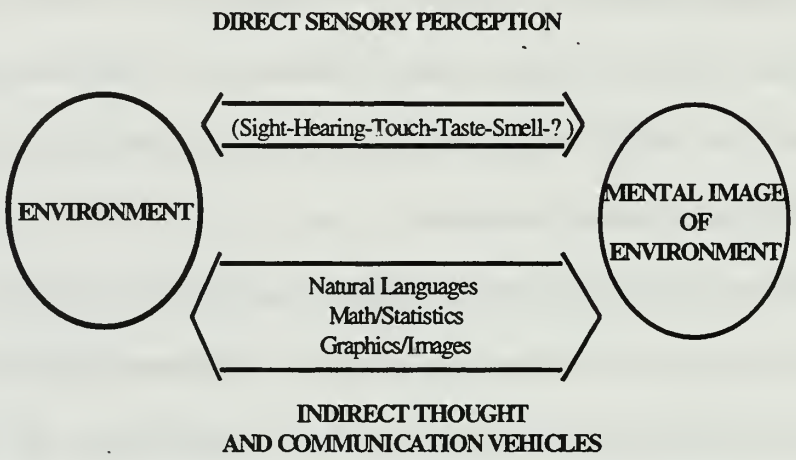


Figure 1. Learning our environment [MUEH92]

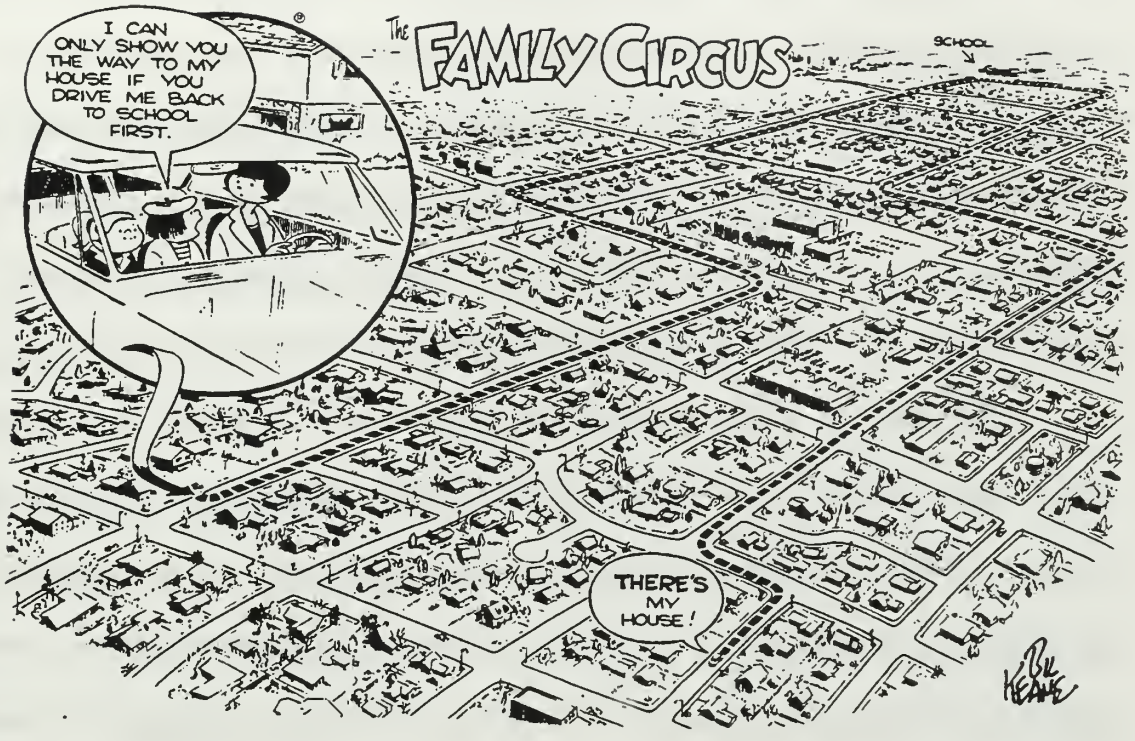

I CAN ONLY SHOW YOU THE WAY TO MY HOUSE IF YOU DRIVE ME BACK TO SCHOOL FIRST.
The FAMILY CIRCUS
SCHOOL
THERE'S MY HOUSE!
BIL KEANE

Figure 2. Mental Map of a Child [MUEH92]

determine how best to manipulate these parameters for our own purpose, which is to optimize the effectiveness of our virtual map representation for any virtual environment.

C. GOALS AND APPROACH

Navigation tasks in large virtual worlds often call for the use of a virtual map. However, all virtual maps are not alike. Performance on navigation tasks in general has been shown to vary depending on the orientation of the map with respect to the user's frame of reference, individual differences, and the characteristics of the virtual environment. Given the importance of navigation to general task performance in large-

scale virtual worlds, maps often have been used as a solution to wayfinding problems. However, the actual benefits and limitations of map use in this new medium are largely unknown. It seems that in most cases, any map is better than no map, especially for very large virtual worlds that are sparsely populated or otherwise generally difficult to navigate. But if a map is to be used, how should it be represented to be most effective? What are the parameters underlying virtual map representation which affect this representation? How can we manipulate these parameters for our own purposes?

The main goal of this thesis is to identify, develop, and test methods for effective virtual map usage for virtual environments as a factor of navigation task. This thesis addresses issues concerning map usage in virtual environments with the assumption that use of a map has already been predetermined. Two virtual environments were created (sparse and dense) with corresponding virtual maps. Participants executed two types of tasks, searching and exploring, to determine map usage effectiveness. These experiments also studied effects of natural human abilities, map orientation, and navigation tasks. The map treatments were the **North-up Treatment,** in which the orientation of the map remains static with respect to the participant, with "North" always at the top of the map, and the **Forward-up Treatment,** in which the orientation of the map remains static with respect to the participant, the forward direction in the world always at the top of the map.

Each subject participating in the experiments:

- took a self-ability evaluation test,
- took the Santa Barbara Sense-of-Direction Scale test,
- took the Guilford-Zimmerman spatial-orientation and spatial-visualization test in order to determine individual differences,

- practiced given tasks in a test environment,
- was tested in virtual environment #1 (Open Ocean) with north-up map,
- was tested in virtual environment #1 (Open Ocean) with forward-up map,
- was tested in virtual environment #2 (Urban) with north-up map,
- was tested the virtual environment #2 (Urban) with forward-up map,

The dependent measures were the test scores, search times and the number of errors made.

D. THESIS ORGANIZATION

This thesis is organized into the following chapters:

- Chapter I: Introduction. This chapter gives a general outline of the work, including the major objective, the motivation behind the thesis, the approach taken which will be expanded upon in subsequent chapters, and the organization of the thesis.
- Chapter II: Background and Previous Work. Current and past studies that relate to the research conducted in this thesis are discussed. This includes mental rotations, individual differences, previous virtual environment map usage, and an overview of video games that use virtual maps and the factors that affect them.
- Chapter III: Approach, Method, and Implementation. This includes the implementations of two virtual environments (open ocean and urban), north-up and forward-up map treatments, and the actual experiments explained in goals and approach.

- Chapter IV: Analysis. This includes the evaluation of data collected.
- Chapter V: Conclusions. This includes a final discussion of the results of this thesis and describes follow-on work to be accomplished.

II. BACKGROUND AND PREVIOUS WORK

This chapter examines current and past studies with regards to mental rotation and individual differences followed by an examination of basic types of maps. Finally, previous electronic virtual environment map usage is reviewed.

A. MENTAL ROTATION

The spatial structure of a place consists of the distances and directions relating its objects, features and events. Observers often produce spatially coordinated action while on the move and plan actions before reaching the station points from which they intend to launch them. This is the case when one plans a route before embarking on a trip. It is implied whenever one launches an act while on the move because the motor plan to control the act must be set before the launching point is reached. Because of this, observers need access to knowledge of the spatial structures of spaces from novel station points [RIES89]. This section explains the observer's abilities to imagine the spatial structure available at novel points of observation and some of the conditions that facilitate access to knowledge.

Geometrically, movements to new points of observation consist of combinations of simple rotation and translation movements. Subjectively, it seems easier to imagine the structure after translations than rotations and after some rotations than others. Theoretically, the relative ease of accessing knowledge of spatial structure at novel station points after rotations versus translations depends on the organization of the

underlying spatial knowledge and processes used to access it. Thus, facts about the relative ease of access can be used to constrain models of the underlying processes and knowledge representations. In addition, they provide an opportunity to explore similarities between imagination, on the one hand, and perception and action on the other [RIES89].

Rotations are more difficult than translations. Imagine being in a building looking at the floor plan (map). If the map is viewed such that it is aligned with the environment, rotation of the map is not necessary. Translation of objects on the floor or determining the position relative to the floor will be easy. If this is not the case, it is necessary to rotate the map or the mental image of the environment in order to match what is seen in the map and what is seen on the floor. The rotations required depend on the individual's training, experience, and abilities. Most people have become disoriented in an environment with which one is already familiar because of looking at the environment from a new point of view. At least it may take some time to match what one had seen with what one had expected to see. As the magnitude of the rotation increases, the time needed in order to compensate for the rotation increases.

As a result, when observers stay in position and imagine the structure available at novel points of observation, they respond as if they directly access knowledge of the object to object relations. For simple translations, little or no additional processing time is needed to judge the directions from the new station. For simple rotations, on the other hand, additional processing is needed, and it varies as a function of the magnitude of

rotation between the object's actual station and the to-be-imagined station point [RIES89].

During navigation, it is common to see people turning maps so the top of the map is congruent with their forward views (forward-up alignment). However, during navigation, some people prefer to orient the map with north at the top so they can easily read the printed information (north-up alignment). The advantage of the forward-up alignment is that the locations of the map symbols are congruent with their actual positions in the forward view. That is, one does not need to rotate the map in order to match the forward view with the actual map representation. With the north-up alignment, there is an incongruency between the information presented on the map (the world reference frame (WRF)) and the perceptual information obtained from the forward view (the ego-centric reference frame (ERF)). How does one compensate for the incongruencies between the two reference frames when they are not aligned [ARET92]?

The answer to this question is very important for construction of virtual maps and their usage in virtual environments. For map usage in the real world, the answer is technologically constrained and therefore very easy. The paper maps can always be physically rotated to the optimum alignment. With virtual maps, however, there are major differences in hardware and software capabilities and requirements [ARET92].

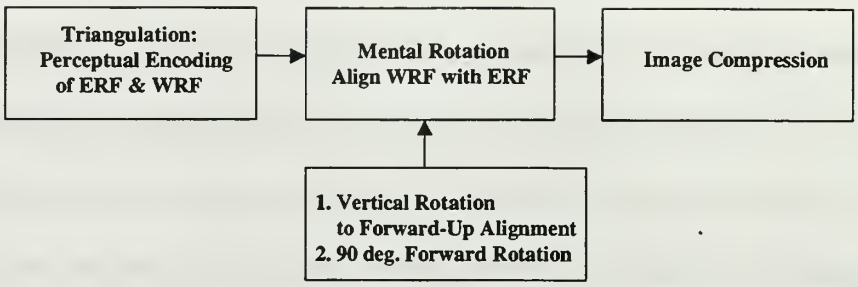


Figure 3. A model of cognitive operations required in the use of a map during navigation [ARET92]

Aretz [ARET90] proposed that four cognitive operations are required during navigation (Figure 3): triangulation, mental rotation, image compression, and translation. The hypothesis stated in [ARET92] is that when the ERF and WRF are not aligned, one of the reference frames must be mentally rotated into congruence with the other in order to compare the information and establish a location in the map.

Levine [LEVI82] provided evidence that some form of mental transformation needs to be performed during navigation by showing that subjects made significantly more errors in using "you are here" maps when the landmarks presented in the tops of the maps did not correspond to what was seen in the forward field of view. The assumption behind the required transformation is that the person using the map must reconcile two cognitive coordinate systems [JUST76]; one that deals with the mental representation of the map and one that deals with the forward view [ARET92].

Many experiments ([ELEY88], [EVAN80], [HINT81], [LEVI82], [ROSS89], [SHEP84], [SHOL87], and [WARR90]) have shown that if the ERF is not aligned with the WRF, a mental rotation must be performed to bring the two reference frames into congruence. Although not always perfectly linear, the time to accomplish this mental rotation has been found to be proportional to the difference between the alignments of two reference frames [ARET92].

One of the most important experiments about mental rotation done by Aretz and Wickens [ARETZ92] investigates the role of mental rotation in the cognitive processing required for map use during navigation. The results showed that humans perform map localization tasks best when both the map and forward view are available for comparison and the map is in a forward-up alignment. When the map is in north-up alignment, mental rotation is the preferred strategy to bring the map into congruence with the forward view [ARET92].

According to the data collected in these experiments, a forward-up (sometimes referred to as "track-up") map may be the best alternative for an electronic navigation display, based on the mental transformation costs of a north-up alignment. Aretz and Wickens [ARETZ92] suggest that a forward-up alignment seems to be best for ERF-based tasks, and a north-up alignment seems best for WRF-based tasks. However, the exact nature of these types of tasks remains somewhat ambiguous.

It is remarkable that all these experiments agree on two important variables that affect navigation performance; map display and navigation task. They conclude that navigation performance seems to be a function of both map display and navigation task.

From this thesis' point of view, this conclusion is accepted as true. However, it is suggested that individual differences and the type of the environment must also be included as two other variables in this function that affect navigation performance.

B. INDIVIDUAL DIFFERENCES

It is suggested that perspective transformation (ERF to WRF and vice versa) may be a trainable skill. While it is not suggested that individuals with low spatial ability can be trained to be comparable to those with high spatial ability, they may be able to raise their general level of performance with repeated exposure to perspective transformation tasks.

The definition of spatial ability is tenuous at best, as it has been studied for most of this century. To this date, a consensus has not been reached and it remains an "ill-defined concept". What is agreed upon is that spatial ability is comprised of various dimensions. The three major dimensions of spatial ability that are commonly addressed are spatial orientation, spatial visualization, and spatial relations. Spatial orientation involves the ability to mentally move or transform stimuli while retaining their relationships. Spatial orientation also involves the mental manipulation of an object using oneself for reference. Spatial visualization goes further, in that the person can manipulate the relationships within an object. The third dimension, spatial relations, consists of the ability to imagine how an object will align from different perspectives [SATA95].

Spatial ability is usually measured by psychometric tests. A problem with these tests is that they present problems using small-scale objects whereas most of our

interaction with the real world is in large-scale spaces. Small-scale refers to an object or environment that can be seen in its entirety from at least one viewpoint. Large-scale spaces must be learned from sequential exposures. It was not until recently that one of these spatial ability tests, the Guilford-Zimmerman Spatial Orientation Test, was shown to predict performance in a large-scale space. At present, the other psychometric tests measuring spatial relations and visualization have not been validated for large-scale space performance [SATA95].

In this thesis, the Guilford-Zimmerman Spatial Orientation and Spatial Visualization Test was used in order to determine individual differences. In the spatial visualization part, each subject was asked to imagine how a clock object would look if it were rotated as indicated by the arrows on a sphere object. In the spatial orientation part, the subjects were shown two photographs of a shoreline taken from a boat and were asked to imagine themselves looking over the prow of the boat. Subjects were then asked what changes in the boat's orientation have occurred between the time the two photographs were taken. In [CARP82], this process is described as "*Subjects are asked to represent the perspective of the shoreline within a cognitive coordinate system defined by the visual world as seen from the boat, and to compute the transformation that caused a given change in perspective*". Chapter IV of this thesis talks about the results of these experiments and their effects in navigational performance in more detail.

C. DIFFERENT ENVIRONMENTS, DIFFERENT MAPS

Maps serve many purposes beyond just navigation aids. Maps are used as computational devices by engineers and as mobility aids by navigators. They may be used to summarize volumes of statistical data or to explore data for clusters, trends, or correlations. Sometimes people want a map to help them visualize what otherwise would be invisible. Maps may also be used as a trigger device to stimulate thought [MUEH92]. Maps are used in complex buildings such as shopping malls as well as in video games to save the princess who is lost in a labyrinth.

Considering these many purposes, it is obvious that one design cannot serve all needs equally well. In fact, the purpose of a map is actually the most important constraint of a map. Combining many purposes in a map can greatly affect the map user's ability to use it effectively. That's why people need different types of maps for different environments.

All maps are symbolic. But not all symbology is the same. The most realistic map symbols are the miniature three-dimensional objects such as buildings, trees, and cars that are used to make large-scale physical models. But constructing these physical models by using three-dimensional objects is expensive and they are difficult to modify after construction. On the contrary, from the point of view of virtual maps, this method is easy to use and modify compared to real life. Another method is to use photographic symbols, which provide the most "true-to-nature" [MUEH92] coordinations with real life features. One disadvantage of photographs is that most environmental features appear in true relative scale meaning that only those features large enough to be seen from the

vantagepoint of the camera will be mapped. Another disadvantage is that photos are restricted to tangible phenomena [MUEH92]. But the graphics method of representing map symbols is the most common method (Figure 4). These graphic symbols can range widely in appearance. Some symbols look quite natural while others are totally abstract. The type of symbolism varies with map scale, pattern complexity, and intended audience [MUEH92].

Figure 4. An early world map, circa 600 B.C., shows Babylon as a rectangle intersected by two vertical lines representing the Euphrates River. Small circles stand for surrounding kingdoms, and an ocean encircles the world [NATI98]

The cartographer's map is an external (physical) representation of the environment (Figure 5). It is some graphic or image that can be viewed directly. These

maps come in many forms such as globes, physical models, line drawings, photographs taken from airplanes, and imagery of the earth taken from satellites. These depictions usually have a lasting, tangible form, as when they are sculpted from Styrofoam, printed on paper, or inlaid in a tile floor. But they also may be ephemeral and intangible, as when displayed on a CRT or projected onto a screen [MUEH92].

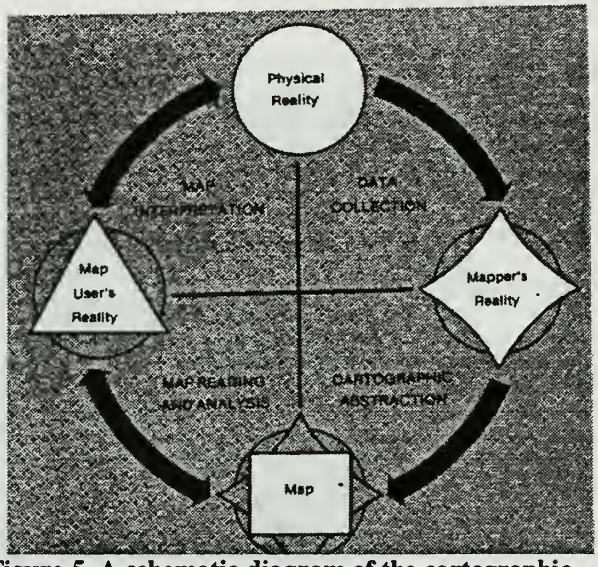


Figure 5. A schematic diagram of the cartographic communication process [MUEH92]

There are two main types of cartographic maps based on design logic. Those whose primary aim is to portray environmental details accurately are called *general-purpose* or *reference maps* (Figure 6). Those whose aim is to depict a general spatial pattern, are referred to as *special-purpose* or *thematic maps* (Figures 6 and 7) [MUEH92].

People usually use *general-purpose* or *reference maps* when they need to establish their location or when they want to know where a place is located in relation to

other environmental features. For example, we immediately look for a floor plan in an unfamiliar building in order to establish our location or we look for a street map of a city when we are visiting that city for the first time. On the other hand, people use *special-purpose* or *thematic maps* in order to get specific information about an environment.

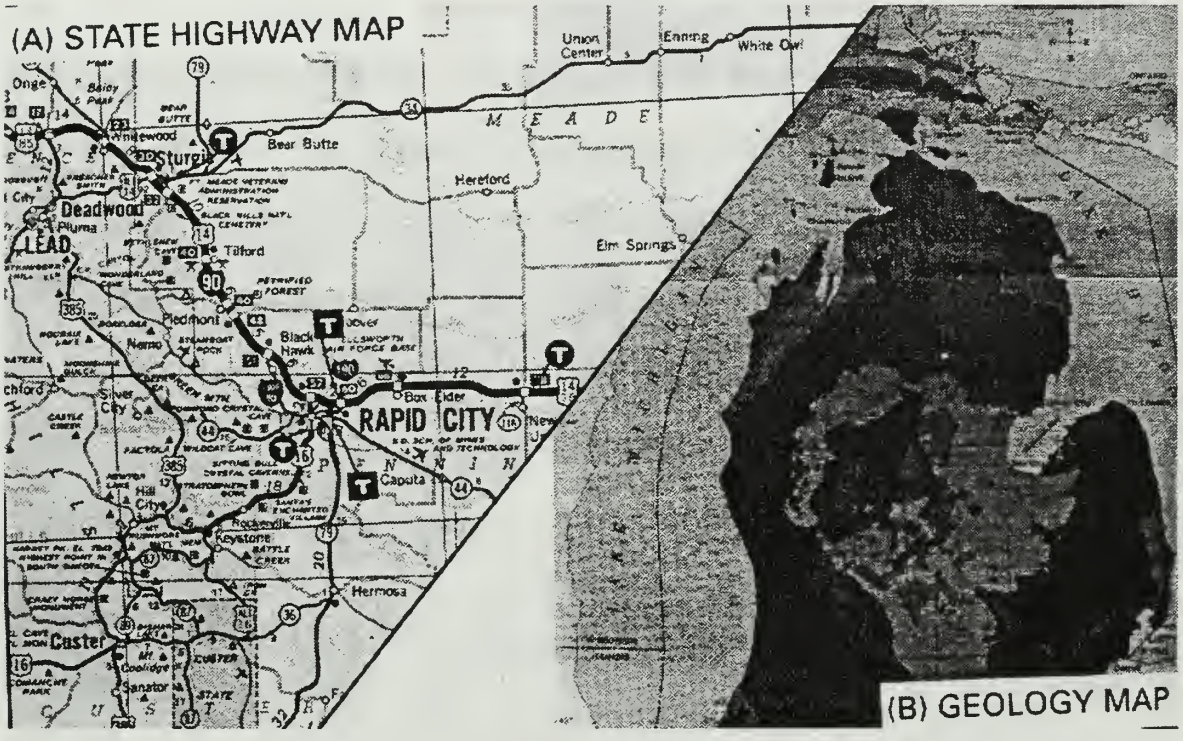


Figure 6. A highway map is a perfect example of a reference map that focuses on a variety of environmental attributes of special interest to motorists. In contrast, a geology map is an example of a thematic map that emphasizes spatial variation of a single attribute-bedrock type [MUEH92]

People need different maps for different environments. Most maps can be grouped under the categories explained above, with the exception of electronic maps which can be dynamic and interactive. Up to date maps are usually designed to aid movement, such as

street maps and floor plans. But they are designed regardless of the state of movement (e.g. active or passive). For instance, a highway map is a perfect example of a passive map because the user must orient the paper map during navigation in order to match the forward view (ERF) with the actual information represented (WRF) on the map. An interesting alternative example is shown in figures 8 and 9. These are highway maps of California specifically designed for drivers who are going to navigate in a northbound or southbound direction. These maps orient the state road system to help those driving from north to south or vice versa. Guided by these maps, the drivers are already oriented in the direction they are headed. That means that one's forward view and the information on the map are already aligned. These maps are inexpensive examples of a pseudo-active map. But electronic maps have the added features of being dynamic and interactive and can handle movement in *any* direction, not just north and south.

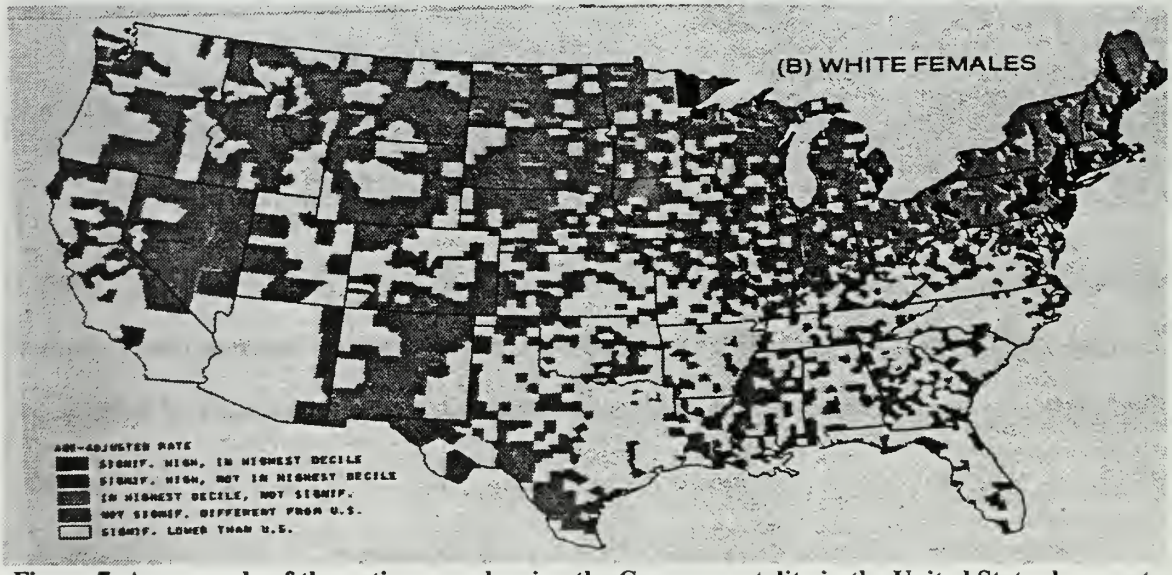


Figure 7. An example of thematic maps showing the Cancer mortality in the United States by country for white females [MUEH92]

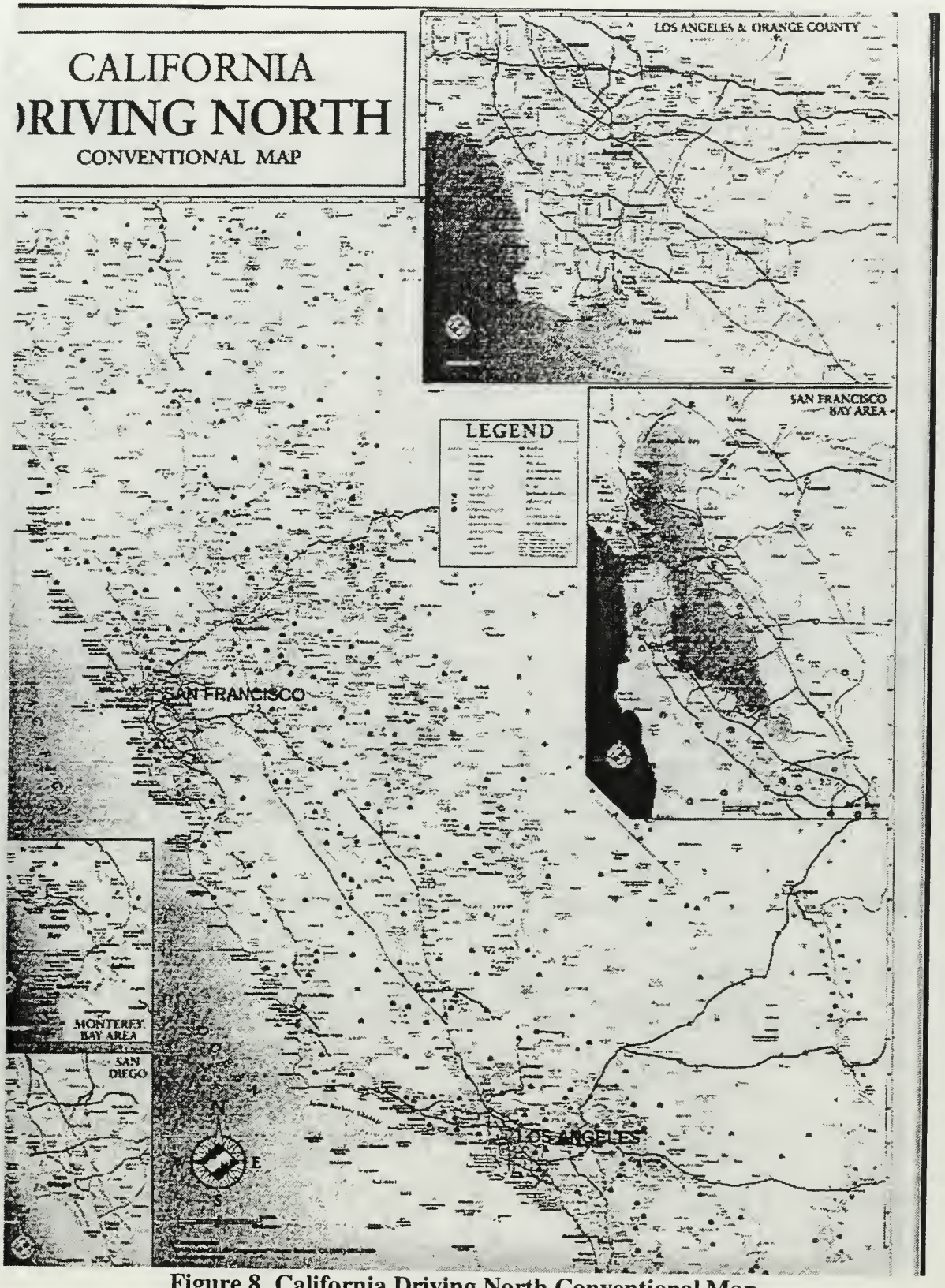


Figure 8. California Driving North Conventional Map

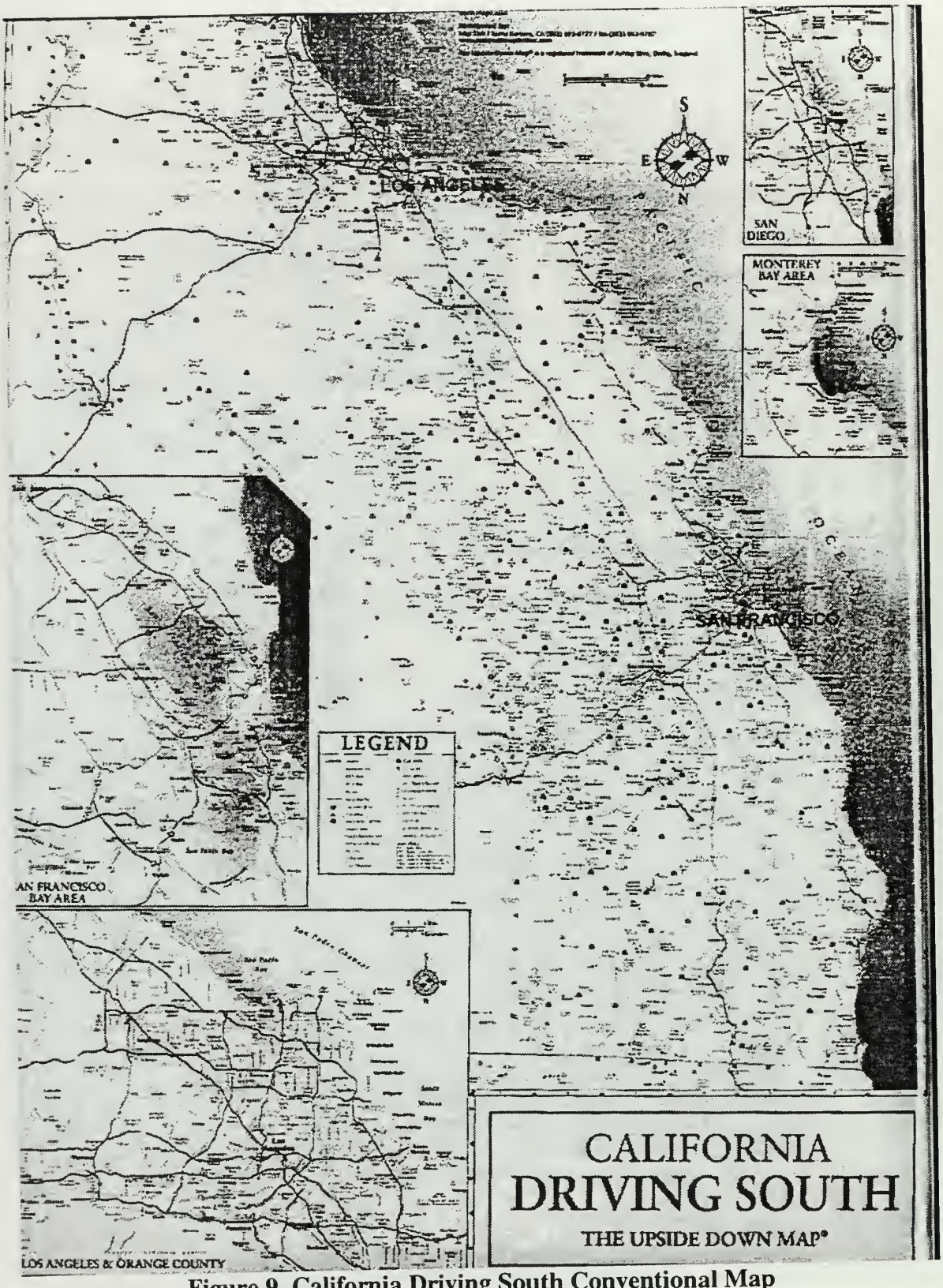


Figure 9. California Driving South Conventional Map

D. ELECTRONIC MAPS

One of the most exciting developments in electronics maps is the use of map displays in vehicle navigation systems. In this application, a base map is shown on a computer screen with the current location indicated. As the car drives along, the position on the map display moves as well. In more sophisticated systems, the map display is linked by cellular phone or radio signals to local databases so that traffic updates and other useful information can be received during travel [MUEH92].

There are currently three main systems that are being used in vehicle piloting systems. The first one is called **inertial navigation** where the device monitors vehicle movements and uses this information to update the position of a YAH cursor on a map display [MUEH92]. One problem with this system is that the driver must initialize the system properly by positioning the cursor at the starting point on the map. Another problem is that each distance and direction computation involves some error. Since each new computation is based on the previous one, these errors accumulate and the actual position of the vehicle shown on the map can be inaccurate.

The second type of these systems is called **radio-navigation technology** which uses ground-based radio beacons in order to determine the actual position of the vehicle. Since each computation of the position of the vehicle is independent of previous ones, this system has advantages over **inertial navigation.**

Although ground-based radio beacons are presently in widespread use, the third type of navigation system, namely the **GPS-linked navigators**, is attracting the most attention. The most important reason for this is that it provides latitude-longitude

coordinates which can be used to retrieve the appropriate map from disk storage. When the vehicle moves off the edge of one map, the next one in the direction of travel is automatically brought up on the display screen [MUEH92]. Most of the current **GPS-linked navigators** used in vehicles allow the driver to create accurate digital maps from any scanned map or existing map database such as BSB Marine Charts or USGS Topographic Maps. In real-time navigation mode, the vehicle's position is shown on the map as the vehicle moves. New maps are automatically loaded as the vehicle travels to new areas. During travel without a computer, these systems allow the driver to position waypoints and routes and upload them to the GPS receiver for use in the field (Figure 10).

Figure 10. Pioneer's GPS-X77 navigation system

Another application of virtual maps is, of course, video games. The video gaming industry has been using virtual maps for years. [COMM97] begins its introduction by saying *"From three-dimensional (3D) graphics on home video games to the special effects and animation sequences created for films, it is apparent that the entertainment industry has emerged as an innovative source of modeling and simulation technology"*.

However, as is the case in the real world, not all video game electronic maps are alike either. From the point of view of this thesis, orientation issues are the priority. Video games that use various orientations for virtual maps are therefore examined.

Before starting to examine video games, it is appropriate to explain the terms associated with orientation with respect to the user, moding, and map-interactivity which will be encountered.

Orientation of the virtual map can be one of the following:

- **User-oriented (Manually oriented)** in which the orientation of the map is controlled entirely by the user.
- **North-up orientation** in which the orientation of the map remains static with respect to the user, with "North" always at the top of the map.
- **Forward-up orientation** in which the orientation of the map remains static with respect to the user, the forward direction in the world always at the top of the map.

The virtual map can be either moded or unmoded.

- The virtual map is **moded** if the user can see either the map or its forward view in the virtual environment, but never both simultaneously.

- The virtual map is **unmoded** if the user can see both the map and its forward view simultaneously.

The virtual map can be interactive, half-interactive, or non-interactive.

- The virtual map is **interactive** if the user can manipulate the YAH marker on the map in order to move in the virtual environment.
- The virtual map is **half-interactive** if the user can interact with the map in some way (i.e. zooming in or out) other than manipulating the YAH marker in order to navigate in the virtual environment.
- The virtual map is **non-interactive** if the user has no means of direct interaction with the map.

Figure 11. Video game Descent's egocentric, 3-D wireframe, User-oriented, moded, half-interactive virtual map

The first game reviewed is Descent (Figure 11), which was created by Parallax Software, along with Interplay Productions. In this video game, the player is a pilot who must rescue hostages and blow up the reactors of certain enemy mines. However, there are many robot drones out to destroy the player before the player destroys them. The virtual map is **user-oriented, moded,** and **half-interactive.** Since the map is moded, the user requires several transitions between the game and the map in order to make the necessary mental rotations to resolve ERF to WRF. In this case, the actual game is ego-centric, but the map is exo-centric and wireframe. The transition from ego to exo is not easy and the lack of objects in the map makes the performing of necessary mental rotations difficult. Using a user-oriented 3D wireframe and moded map without the objects in the actual virtual environment requires high spatial-ability and lots of experience to be effective. The map is **half-interactive.** The player can rotate the map and zoom in or out. From this point of view the map is interactive. But the player cannot manipulate the YAH marker (purple sphere on the map) in order to move in the environment. From this point of view the map is non-interactive.

Jumping Flash (Figure 12), which was created by Sony Computer Entertainment, is a 3D first person perspective, DOOM-like video game. In Jumping Flash, the focus is not shooting, but leaping to the top of skyscrapers and blimps, then jumping down to crush hapless critters while searching for mechanical carrots. Although the environment is 3D, the map is 2D. The map contains no objects in the virtual environment other than the locations of enemies with respect to player's position and orientation. Since the map shows the locations of enemies depending on the player's ERF, it is very easy to perform

Figure 12. Video game Jumping Flash's egocentric, forward-up, non-moded and non-interactive virtual map (Blue blip)

any mental rotation necessary. However, map cannot be used to establish one's location in the virtual environment. But this is not the purpose of the map at all. It's purpose is only to locate targets.

Figure 13. Video game DOOM's egocentric, North-up, moded and interactive virtual map

DOOM, which was created by Id Software, Inc., develops another issue in virtual maps. From the point of view of navigation tasks, it is possible that these tasks can be performed on the map rather than in the environment itself. Since the DOOM map is moded, when in map mode (Figure 13), DOOM players can move themselves in the environment by manipulating the YAH marker on the map. That is why the DOOM virtual map is classified as an interactive virtual map in this thesis. But the effectiveness of this kind of virtual map usage remains as a question. Although the map orientation is north-up, it can be translated horizontally or vertically by the user. It cannot be rotated. Since the map is moded, the game requires several transitions between the game and the map in order to make the necessary mental rotations to resolve ERF to WRF. That's why the game requires very high spatial ability along with experience.

Besides the games explained briefly above, there are many other video games that use virtual maps. From the point of view of this thesis, it is important to note that most of them use a forward-up orientation.

While discussing DOOM, the issue involving navigation tasks that can be performed on the map rather than in the environment itself has come up. The Worlds-In-Miniature (WIM) metaphor takes this further by allowing navigation on the WIM (WRF) while simultaneously updating the ERF perspective [STOA95]. [STOA95] talks about a interaction technique which augments an immersive head tracked display with a hand-held miniature copy of the virtual environment. By establishing a direct relationship between life-size objects in the virtual world and miniature objects in the WIM, the WIM can be used as a tool for manipulating the objects in the virtual environment [STOA95].

III. APPROACH, METHOD, AND IMPLEMENTATION

A. APPROACH

This thesis was intended to investigate the parameters that affect virtual map representation toward a set of principles to assist virtual world builders with map design issues. Previous research and experiments about mental rotation showed that there are two important parameters that affect this representation; map display and navigation task. These experiments conclude that navigation performance seems to be a function of both map display and navigation task. From the point of view of this thesis, this conclusion is accepted as true. However, it is suggested that individual differences and the type of virtual environment must also be included as two other parameters in this function that affect navigation performance. This thesis investigated the following parameters underlying effective virtual map representation.

- Map orientation
- Individual differences
- Spatial characteristic of virtual environments
- Navigation task

Other than the parameters determined by these experiments, the individual differences of users, particularly with respect to mental rotation, are a critical concern. Another parameter is the type of space -- specifically its spatial characteristics such as relative size, object density, etc. Navigating in a dense virtual environment such as an urban virtual environment is different than navigating in a sparse environment such as an open ocean virtual environment. There are lots of objects that can help the user to

establish one's location or to do the necessary mental rotations easily in a dense virtual environment compared to a sparse virtual environment. Lastly, this thesis is interested in how performance of different navigation tasks is affected by all of these factors. Different tasks require different types of information and consequently, should be affected by map orientation and individual differences.

B. METHOD

The experiment designed for this thesis examined users of an urban and an open ocean virtual environment executing a set of navigation tasks with each of two maps with different orientation schemas.

Navigation tasks are coarsely defined to be either searching or exploration tasks [TEMP95][DARK96a]. For this thesis, the following navigation tasks were used:

- *Targeted search*: A searching task in which the target in question is shown on the virtual map. The search is non-exhaustive.
- *Primed search*: A searching task in which the location of the target is known, but the target does not appear on the virtual map. The search is presumed to be non-exhaustive.
- *Naïve search*: A search task in which there is no a priori knowledge of the whereabouts of the target in question and the target is not shown on the map. A naïve search implies that an exhaustive search must be performed. An optimal exhaustive search requires that the navigator traverse the entire space once (in the worst case).
- *Exploration*: A wayfinding task in which there is no specific target.

Exploration was not explicitly examined in this thesis but it is clearly intertwined with searching tasks to some degree. In addressing the needs of all of these categories, virtual maps must support both exhaustive and non-exhaustive searches and must facilitate acquisition of configuration knowledge.

The performance of each participant was observed and measured on each navigation task in both the urban and open ocean virtual environments. While each participant received a condition in both types of environment, they only received one type of map treatment. The order of their treatments was predetermined at random. The two map treatments in this thesis were:

- *North-up Treatment*: The orientation of the map remains static with respect to the participant. The top or "north" is always at the top. The YAH marker is represented as a cone with origin at the viewpoint (Figure 14, 15).
- *Forward-up Treatment*: The orientation of the map remains static with respect to the world. The forward direction in the world is always at the top. The YAH marker is represented as a sphere (Figure 16, 17).

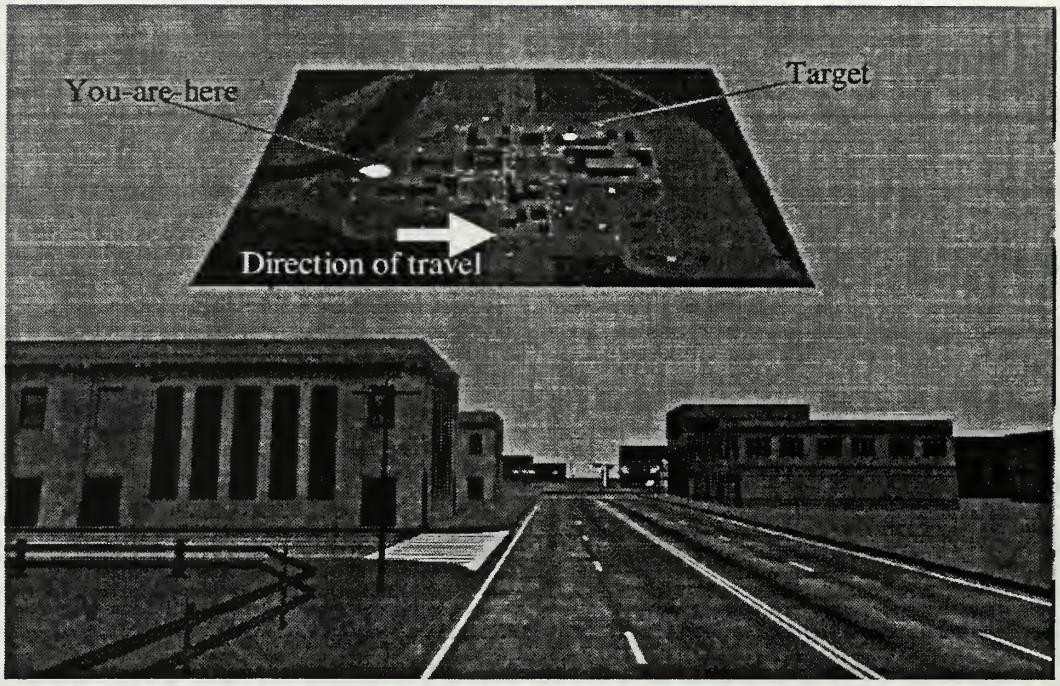


Figure 14. North-up Map Treatment in the Urban Virtual Environment

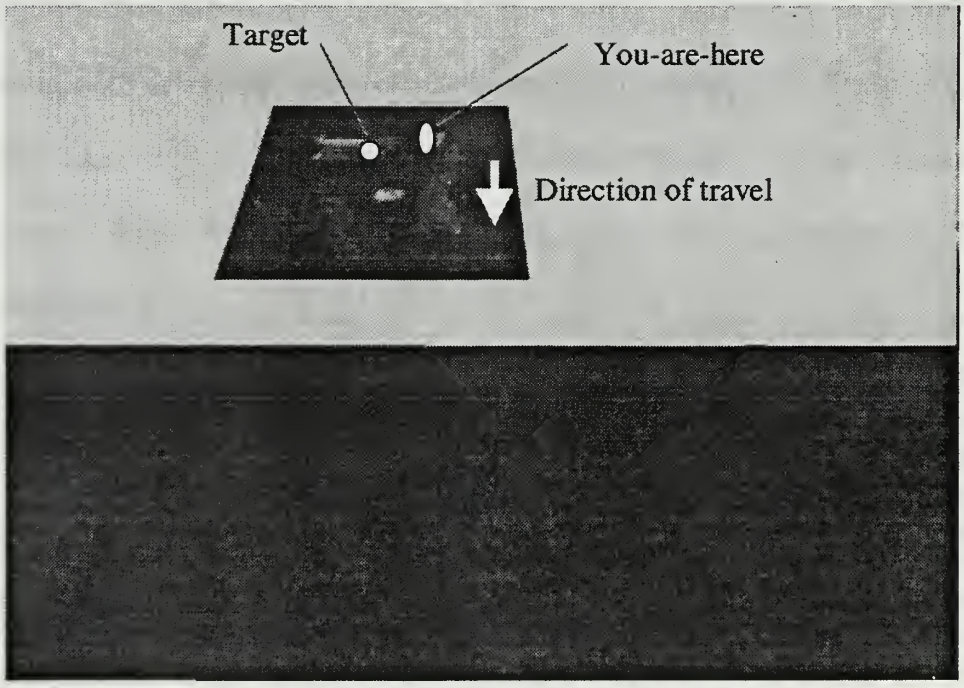


Figure 15. North-up Map Treatment in the Open Ocean Virtual Environment

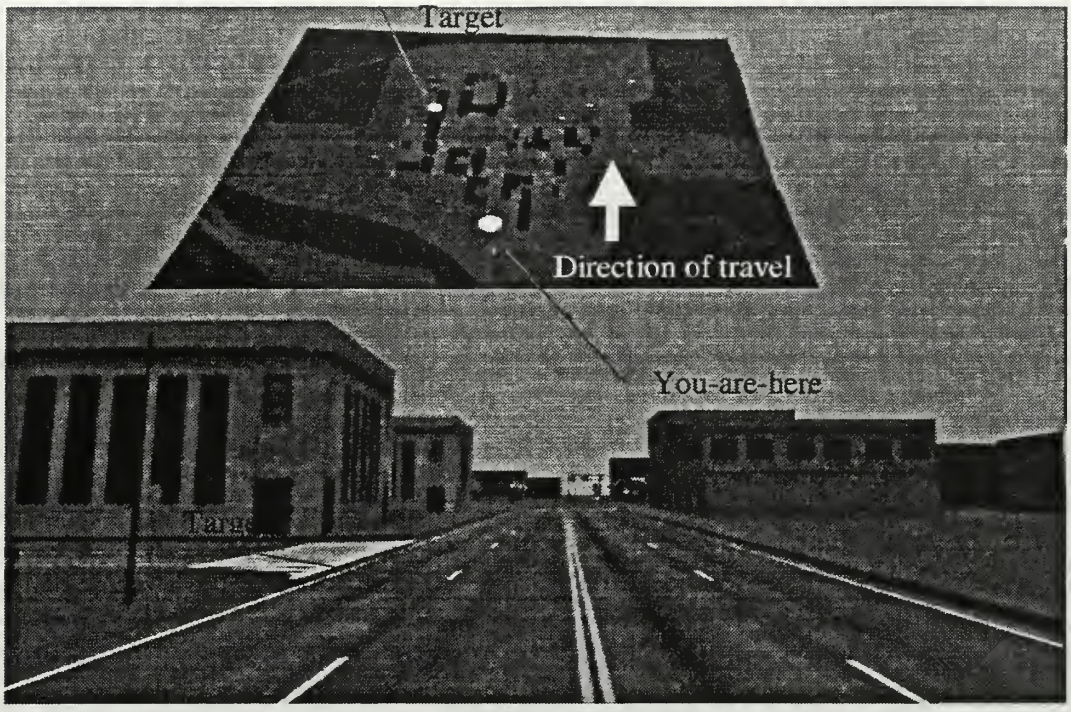


Figure 16. Forward-up Map Treatment in the Urban Virtual Environment

In figures 14 and 16, the forward view in both figures is the same. However, the orientation of the virtual maps is different. This is also true for figures 15 and 17.

Besides these two treatments, a third one can be encountered both in papers about map orientation and video games. This treatment is called *Manually oriented* -- sometimes referred to as *user-oriented*-- map treatment. This third map condition, where the map is not automatically oriented in any fashion but rather is oriented entirely by the user by rotating via a tracker held in the user's hand, was also considered in this thesis. This was of interest because it most closely resembles the use of paper maps in the real world. It was of interest whether users would attempt to replicate the forward-up map or the north-up map. The answer seems to be neither [DARK99]. The task of searching for targets, when combined with the task of keeping the map aligned properly seems to be

more than the average person can handle. They quickly lose track of how the map should be oriented and consequently, they stop using it. It was determined from the results of an earlier pilot study that this type of map was far inferior in terms of performance to the other two types of maps on all categories of search tasks. Therefore, the *manually oriented map treatment* was not investigated in the experiments.

In order to determine the effects of differences in spatial ability between the participants, two groups of tests were applied to participants. The first two tests allowed the participants to evaluate themselves while the Guilford-Zimmerman spatial visualization (SV) and spatial orientation (SO) tests provided the actual spatial ability of each participant. For these tests, participants were given unlimited time to examine the examples presented in the test booklets and were given explanations to any questions they had both before the test and during the actual test.

- *The Self-Ability Evaluation Test (SAE):* SAE (Appendix-B) is a qualitative self-analysis of an individual's navigational ability. The SAE provides a participant with general limits from which to appraise one's perceived navigation aptitude.
- *Santa Barbara Sense-*of-*Direction Scale Test (SBSODS):* The SBSODS (Appendix-C) is a quantitative self-evaluation of navigational ability.
- *Guilford-Zimmerman Spatial Visualization Test (SV):* In SV each participant was asked to imagine how the clock object would look if it were rotated as indicated by the arrows on the sphere object.
- *Guilford-Zimmerman Spatial Orientation Test (SO):* In SO the participants were shown two photographs of a shoreline taken from a boat and were asked to imagine themselves looking over the prow of the boat. Participants were then

asked what changes in the boat's orientation have occurred between the time the photographs were taken.

Before beginning the VE portion of the experiment, each participant was given a period of time on a separate practice VE to become familiar with the Fakespace Inc. PUSH device and the movement mechanism inherent to that device. During trials, the paths each participant traversed through each assigned navigation task were sampled (approximately once per second) for later analysis and task completion times were taken.

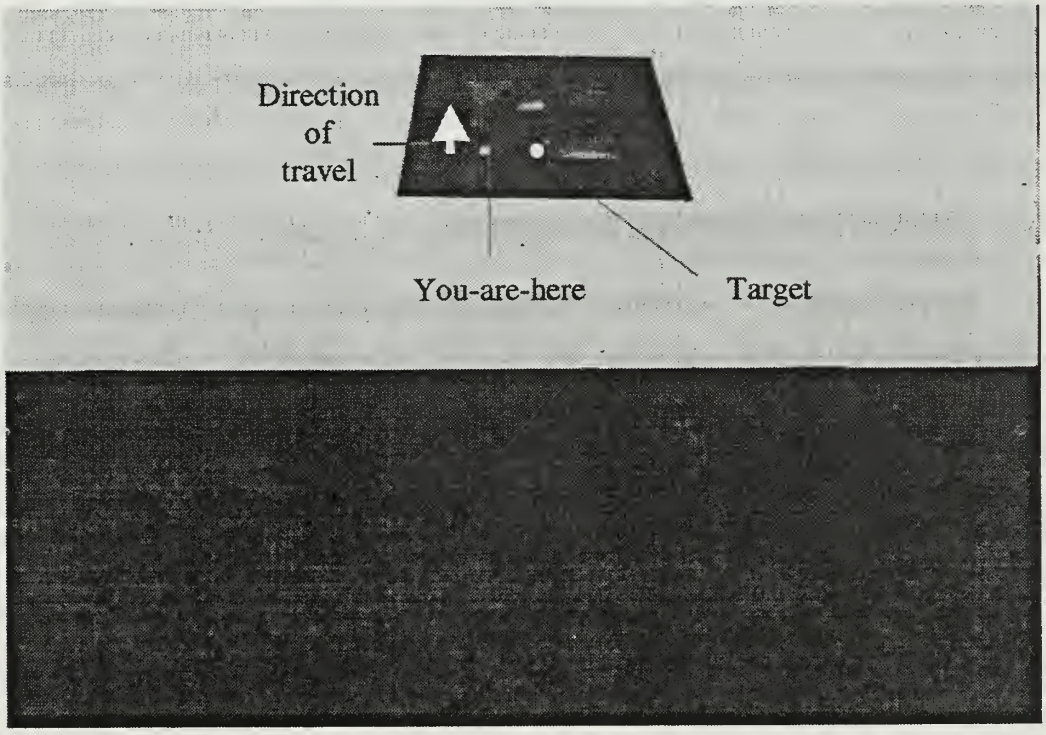


Figure 17. Forward-up Map Treatment in the Open Ocean Virtual Environment

During task execution, participants were asked to "think aloud" [ERIC93] as a method of knowledge elicitation specifically aimed at understanding search strategies. In addition to

task completion times, errors were analyzed, defined as "wrong turns" where participants turned away from the target rather than towards it, presumably due to mental rotation errors.

The navigation tasks performed for all treatments required the participant to execute three targeted searches, followed by three primed searches, followed by one naïve search. For the targeted searches, a colored target (red, green and blue) appeared on the map, one at a time. Then, the participant was instructed to return to each of the three previous targets but no visual feedback was given on the map. These are the primed searches. Finally, the participant was asked to locate a target not seen before and with no visual feedback on the map. This is the naïve search.

C. DESIGN AND IMPLEMENTATION

30 participants (4F / 26M) took part in the experiment. They were divided into two groups of fifteen at random with the constraint that each group is balanced with respect to spatial ability scores. All participants had a technical background and were between the ages of 25 and 36.

There were two VEs used for this experiment: an urban VE (UVE) and an open ocean VE (OOVE). A modified version of Performer town is used for the UVE. The OOVE was manually constructed using a geometric modeling tool. The OOVE contains large areas of open sea with four land masses. The land masses are shaded by elevation and the ocean surface is textured. The land masses were shaped and scaled to be distinct from one another. The targets (colored spheres) were manually placed in worlds. These environments were selected due to their spatial characteristics. An area of interest was

whether or not objects in a space (or lack thereof) would have an effect on performance or strategy.

The viewpoint could not be moved vertically in either environment and was fixed at three meters in elevation. Movement was also constrained horizontally so that when an edge was encountered, it could not be used as a navigation aid.

The virtual maps used in both treatments were identical to their corresponding environment. A YAH marker was moved along the map surface to identify the viewpoint and to establish location in the actual VE. The YAH marker was a white sphere in the forward-up map treatment and a red cone approximating the view volume for the north-up map treatment. This difference was due to the fact that the forward-up configuration preserves relative direction information while the north-up configuration does not. However, this fact in and of itself does not account for any obvious benefit as long as the YAH marker in the north-up treatment shows view direction.

The virtual maps were presented tilted by 45° and above the actual VE. The maps were unmoded, meaning that participants can view both the map and the forward view simultaneously. The maps were not interactive and could not be directly manipulated by the participant.

The treatments were implemented on a Silicon Graphics Onyx Infinite Reality graphics workstation. A Fakespace Inc. PUSH display and tracker (Figure 18) was used for head tracking and visual display. The PUSH is a full color, high-resolution device that provides full six-degree of freedom movement in the VE. The display is held to the eyes with two hands. The position and orientation of the head are tracked through three mechanical joints. Motion is controlled via an acceleration metaphor by which the

participant accelerates forward in the VE by pushing the display forward or decelerates by pulling the display backwards. Movement can be forward or backward but is always in the direction of view. The participant may stop at any time by releasing the display.

Figure 18. The Fakespace PUSH Device

IV. ANALYSIS

A. EXPLORING THE EFFECT OF MAP TYPES ON NAVIGATION PERFORMANCE

A selection of 13 participants was taken out of the two groups (Forward-Up and North-Up Groups). The outliers encountered in the regression analysis (See next section, A Regression Model to Estimate the Effect of Individual Differences, for details) were eliminated. The two groups were selected according to their familiarization in navigation, computer games, and their SV scores. The reason for taking SV results into consideration, but not SO results, is the relatively more powerful effect of SV results in

Forward-up Group Participant No	SV Score	SV Score	North-up Group Participant No
23	3.75	5	13
18	9	9.5	3
28	13.5	11.25	9
25	13.5	12	1
22	16.25	19.75	14
29	19	20.25	5
30	20	21	8
19	21.75	21.25	12
17	22.25	21.5	11
27	23.75	21.5	7
16	24	22	2
24	26.5	22	10
20	28	29	4
Average	18.56	18.15	Average

Table 1: Selected Participants according to their SV Scores and Backgrounds

navigation in both virtual environments than the SO scores.

1. **Checking the distribution of the two selected groups according to their SV scores**

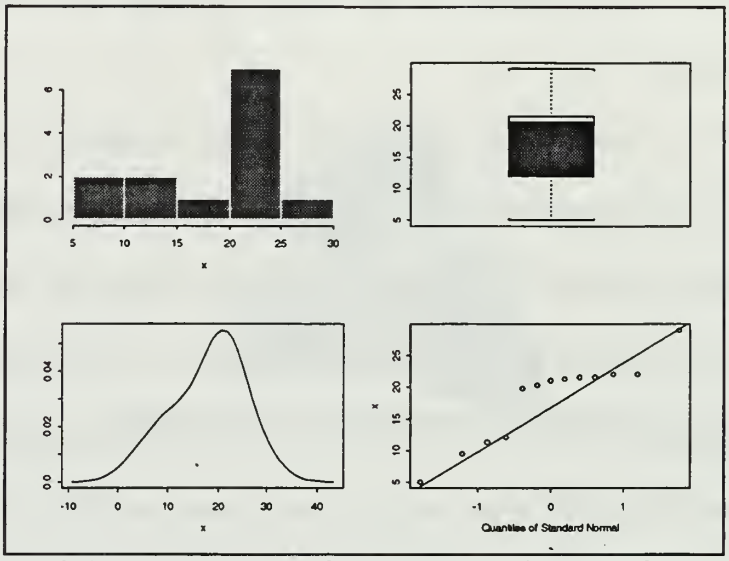


Figure 19. The Data Plots of Participants Selected from North-up Map Group

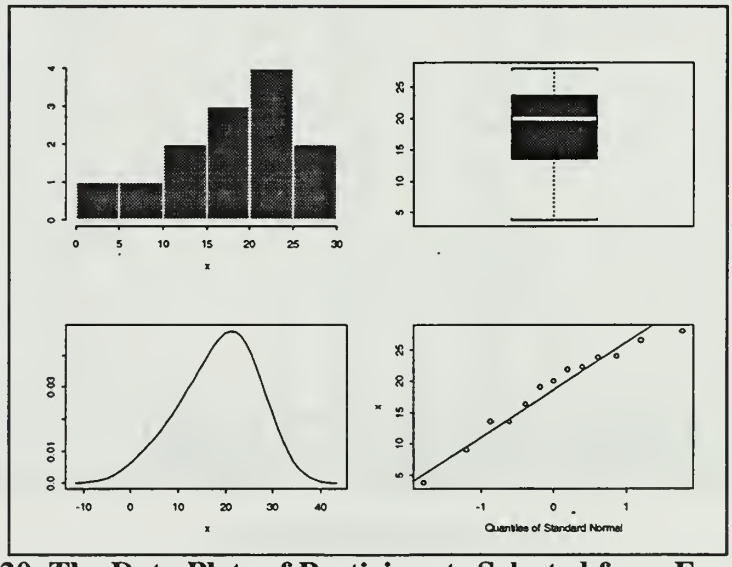


Figure 20. The Data Plots of Participants Selected from Forward-up Map Group

Figures 19 and 20 show that both groups are coming from a Positively Skewed Distribution (A positively skewed distribution is heavier to the right of the median).

2. **Comparing the mean SV scores for the North-up Group and the Forward-up Group**

Hypothesis Test:

Null Hypothesis H_0: There is no difference between the mean SV scores of the North-up Map Group and the Forward-up Map Group.

Alternative Hypothesis H_1: There is a difference between the mean SV scores of North-up Map Group and the Forward-up Map Group.

or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$
$$H_1 : \mu_{north} - \mu_{forward} \neq 0$$

Level of Significance: α=0.05.

Statistical Test: Since the sample size is relatively small, a two-sample t-test was preferred. However, the model assumptions must be checked for the test. Two-sample t-test assumes that the samples are independent and normally distributed with equal variance. Figures 19 and 20 show that the samples are coming from a positively skewed distribution. Therefore, our normality assumption fails. We can apply logarithmic or square root transformations to both samples and make them normal. For these samples a logarithmic transformation works better. Figure 21 displays the diagnostic plots applied to the samples after the logarithmic transformation.

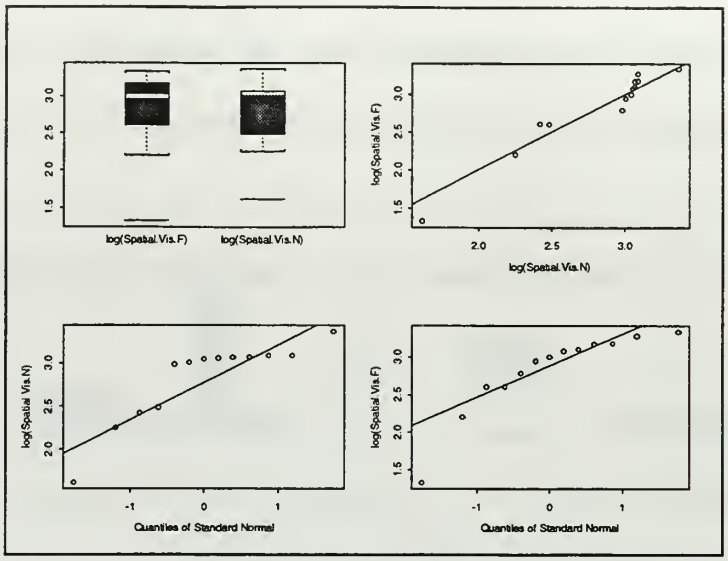


Figure 21. Diagnostic Plots to Check the Model Assumptions Applied to the Logarithm of the Data

The box-plot and Quantile-Quantile (QQ) Plot in Figure 21 show that the samples have approximately equal variance. The Quantiles of Standard Normal Plots support the normality assumption except the outliers as seen in the lower-left corner.

Standard Two-Sample t-Test :

```
> t.test(log(Spatial.Visualization.North),log(Spatial.Visualization.Forward))
        Standard Two-Sample t-Test
data:  log(Spatial.Visualization.North) and log(Spatial.Visualization.Forward)
t = -0.0174, df = 24, p-value = 0.9863
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.4228451  0.4157856
sample estimates:
 mean of x mean of y
  2.811052  2.814582
```

Table 2: The S-Plus Output of the Standard Two Sample t-Test

Since the 95% confidence interval covers 0, and the p-value is 0.9863 (which is greater than the level of significance), we fail to reject the null hypothesis.

Conclusion: The standard two-sample t-test supports the assumption that both samples have equal means.

Both the plots and the t-test support that both samples are coming from a similar distribution with an approximately equal mean and variance.

Now we analyze the effect of map type on the Computer Navigation scores by comparing the scores for the selected groups.

3. Effect of Map Type on the Urban Targeted Scores

Hypothesis Test:

Null Hypothesis H_0: Map type has no effect on the Urban Targeted Scores.

Alternative Hypothesis H_1: Mean North-up Urban scores are greater than mean Forward-up Urban scores.

or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$
$$H_1 : \mu_{north} - \mu_{forward} > 0$$

Level of Significance: α=0.1

Statistical Test: Since the sample size is relatively small, a two-sample t-test was preferred. However, the model assumptions must be checked for the test. Two-sample t-test assumes that the samples are independent and normally distributed with equal variance. Figure 22 shows the diagnostic plots to check the model assumptions. The Quantiles of Standard Normal Plots do not support the normality assumption.

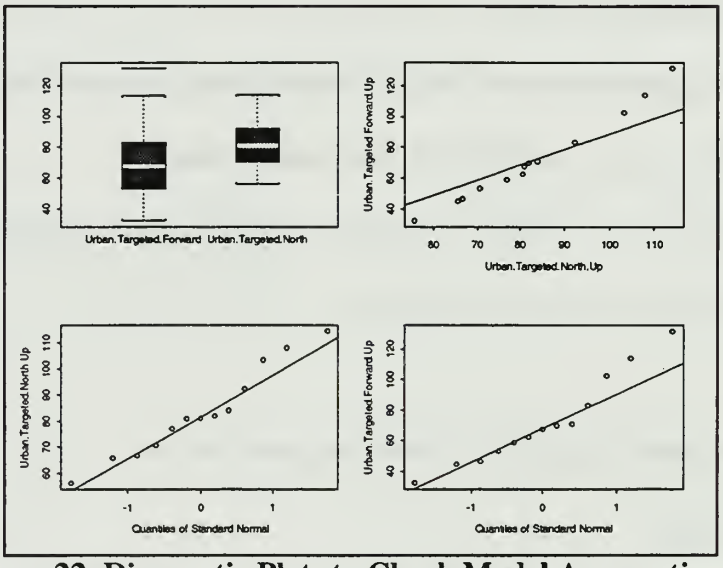


Figure 22. Diagnostic Plots to Check Model Assumptions

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. The Quantiles of Standard Normal Plots do not support the normality assumption.

A logarithmic transformation is applied to satisfy the normality assumption. Figure 23 displays the diagnostic plots after the logarithmic transformation.

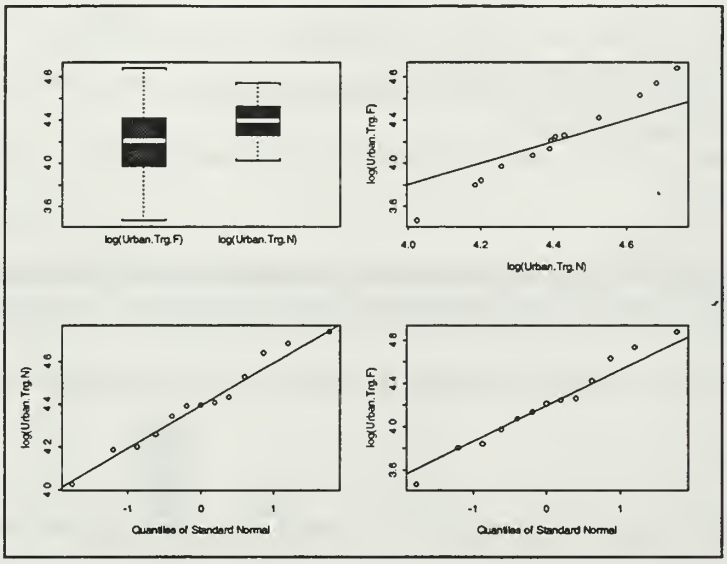


Figure 23. Diagnostic Plots to Check the Model Assumptions Applied to the Logarithm of the Data

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. However, the Quantiles of Standard Normal Plots support the normality assumption.

Welch Modified Two-Sample t-Test: Since the variances are not equal, we apply Welch Modified Two-Sample t-Test to the logs of the samples.

```
> t.test(log(Urban.Targeted.North.Up),log(Urban.Targeted.Forward.Up),
var.equal=FALSE,alternative="greater")

        Welch Modified Two-Sample t-Test

data:  log(Urban.Targeted.North.Up) and log(Urban.Targeted.Forward.Up)
t = 1.5946, df = 18.13, p-value = 0.064
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -0.01723626         NA
sample estimates:
 mean of x mean of y
  4.401419  4.203457
```

Table 3: The S-Plus Output of Welch Modified Two-Sample t-Test

Since the p-value is 0.064 which is less than the level of significance, we reject the null hypothesis.

Conclusion: With a 0.1 level of significance, we conclude that the Forward-up map type is better than North-up map for targeted search performance in the UVE.

4. Effect of Map Type on the Urban Primed Scores

Hypothesis Test:

Null Hypothesis H_0: Map type has no effect on the Urban Primed Scores.

Alternative Hypothesis H_1: Mean North-up Urban scores are less than mean Forward-up Urban scores.

or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$
$$H_1 : \mu_{north} - \mu_{forward} < 0$$

Level of Significance: α=0.1

Statistical Test: Since the sample size is relatively small, a two-sample t-test was preferred. However, the model assumptions must be checked for the test. A Two-sample t-test assumes that the samples are independent and normally distributed with equal variance. Figure 24 shows the diagnostic plots to check the model assumptions. The Quantiles of Standard Normal Plots do not support the normality assumption.

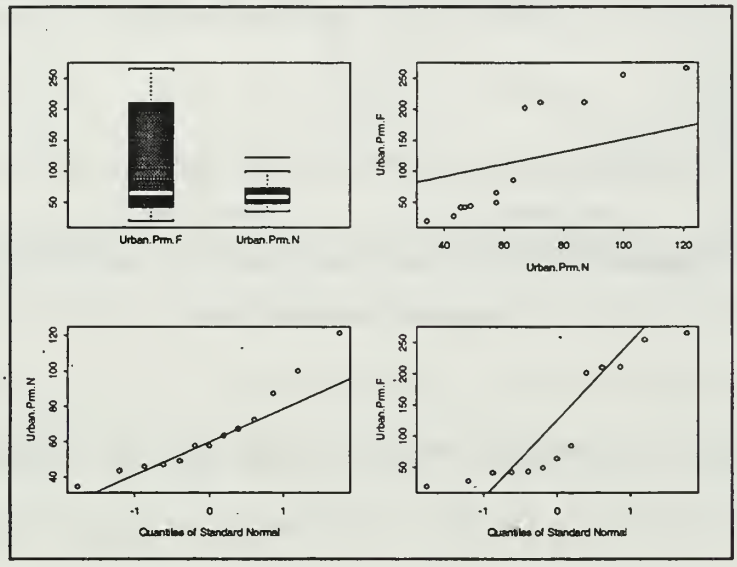


Figure 24. Diagnostic Plots to Check the Model Assumptions

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. The Quantiles of Standard Normal Plots do not support the normality assumption.

A logarithmic transformation is applied to satisfy the normality assumption. Figure 25 displays the diagnostic plots after the logarithmic transformation.

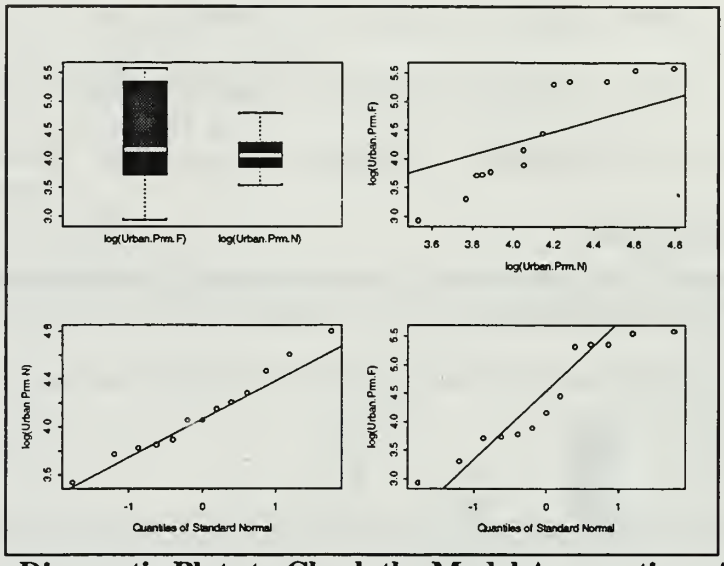


Figure 25. Diagnostic Plots to Check the Model Assumptions Applied to the Logarithm of the Data

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. However, the Quantiles of Standard Normal Plots support the normality assumption.

Welch Modified Two-Sample t-Test: Since the variances are not equal, we apply Welch Modified Two-Sample t-Test to the logs of the samples.

```
> t.test(log(Urban.Primed.North.Up),log(Urban.Primed.Forward.Up),
var.equal=FALSE,alternative="less")

        Welch Modified Two-Sample t-Test

data:  log(Urban.Primed.North.Up) and log(Urban.Primed.Forward.Up)
t = -0.9849, df = 15.48, p-value = 0.1699
alternative hypothesis: true difference in means is less than 0

95 percent confidence interval:
     NA 0.2111711
sample estimates:
 mean of x mean of y
  4.113972  4.386013
```

Table 4: The S-Plus Output of Welch Modified Two-Sample t-Test

Since the p-value is 0.1699, which is greater than the level of significance, we fail to reject the null hypothesis.

Conclusion: With a 0.1 level of significance, t-test supports that the means of the samples are equal. This is a very interesting result. We expect to see the North-up map results to be much better than the Forward-up map results. However, if we carefully analyze the data, we notice that the participants with high spatial ability have better results than those of the North-up map group. On the contrary, the participants with low spatial ability have relatively worse scores than those of the North-up map group. This results in a balance between the bad results and good results of the Forward-up map group.

5. Effect of Map Type on the Ocean Targeted Scores

Hypothesis Test:

Null Hypothesis H_0: Map type has no effect on the Ocean Targeted Scores.

Alternative Hypothesis H_1: Map type has an effect on OOVE Targeted search scores.

or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$
$$H_1 : \mu_{north} - \mu_{forward} > 0$$

Level of Significance: α=0.1

Statistical Test: Wilcox Rank Sum Non-parametric Test is applied to the model.

```
Wilcoxon rank-sum test
data:  x: Ocean.Targeted.North.Up , and y: Ocean.Targeted.Forward.Up
rank-sum normal statistic with correction Z = 2.3598, p-value = 0.0091
alternative hypothesis: true difference in means is greater than 0
```

Table 5: The S-Plus Output of Wilcox Rank Sum Non-parametric Test

Since the p-value is 0.0091, which is less than the level of significance, we reject the null hypothesis. Wilcox Rank Sum is a Non-Parametric Test. Once a non-parametric test results in rejecting the null hypothesis, then it is not required to apply a parametric test.

Conclusion: With a 0.01 level of significance, Wilcox Rank Sum Non-parametric Test supports that the mean of the Forward-up Ocean Targeted Search Scores is better than those of the North-up group.

6. Effect of Map Type on the Ocean Primed Scores

Hypothesis Test:

Null Hypothesis H_0: Map type has no effect on the Ocean Primed Scores.

Alternative Hypothesis H_1: Map type has an effect on the Ocean Primed Scores.

or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$
$$H_1 : \mu_{north} - \mu_{forward} \neq 0$$

Level of Significance: α=0.1

Statistical Test: Since the sample size is relatively small, a two-sample t-test was preferred. However, the model assumptions must be checked for the test. The two-sample t-test assumes that the samples are independent and normally distributed with equal variance. Figure 48 shows the diagnostic plots to check the model assumptions. The Quantiles of Standard Normal Plots do not support the normality assumption.

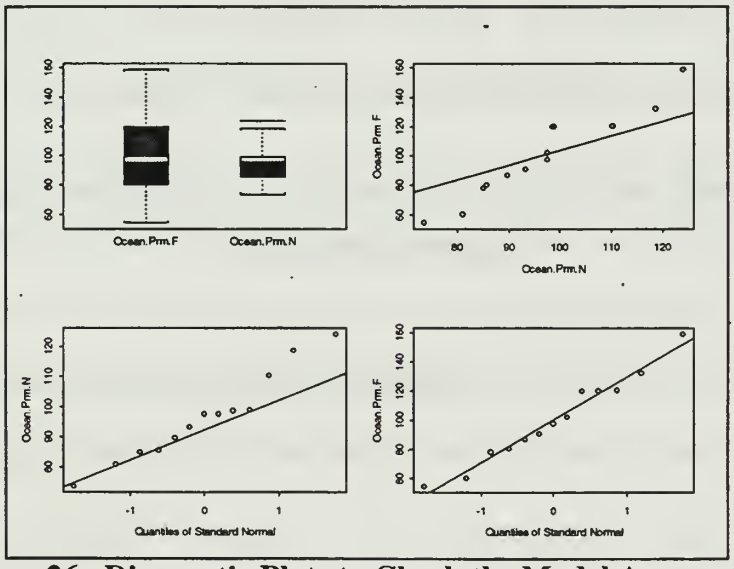


Figure 26. Diagnostic Plots to Check the Model Assumptions

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. The Quantiles of Standard Normal Plots do not support the normality assumption.

A logarithmic transformation is applied to satisfy the normality assumption. Figure 27 displays the diagnostic plots after the logarithmic transformation.

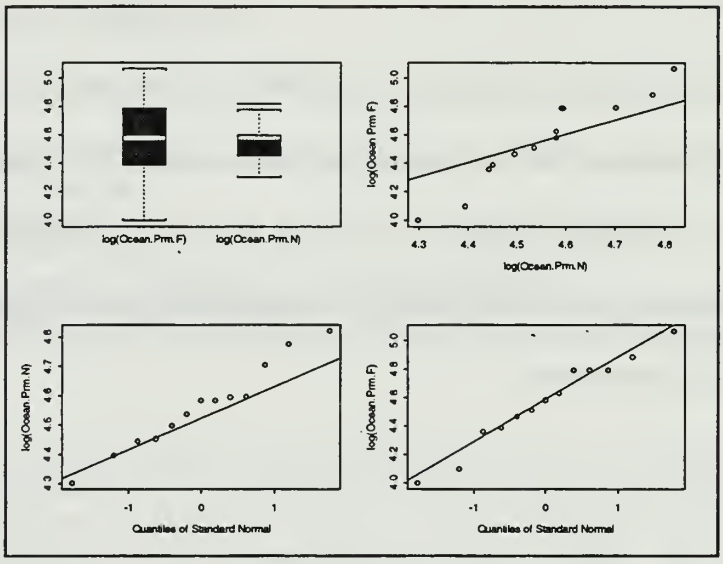


Figure 27. Diagnostic Plots to Check the Model Assumptions Applied to the Logarithm of the Data

The box-plot and Quantile-Quantile (QQ) Plot show that the samples do not have equal variance. However, the Quantiles of Standard Normal Plots support the normality assumption.

Welch Modified Two-Sample t-Test: Since the variances are not equal, we apply a Welch Modified Two-Sample t-Test to the logs of the samples.

```
> t.test(log(Ocean.Primed.North.Up),log(Ocean.Primed.Forward.Up), var.equal=FALSE)

        Welch Modified Two-Sample t-Test

data:  log(Ocean.Primed.North.Up) and log(Ocean.Primed.Forward.Up)
t = -0.0404, df = 17.266, p-value = 0.9682
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.2038874  0.1962155
sample estimates:
 mean of x mean of y
  4.559205  4.563041
```

Table 6: The S-Plus Output of Welch Modified Two-Sample t-Test

Since the p-value is 0.9682 which is greater than the level of significance, we fail to reject the null hypothesis.

Conclusion: With a 0.1 level of significance, t-test supports that the mean of the samples are equal. We expect to see North-up map group's results to be much better than the Forward-up map group's results. However, if we carefully analyze the data, we notice that the participants with high spatial ability have better results than those of North-up map group. On the contrary, the participants with low spatial ability have relatively worse scores than those of the North-up map group. This results in a balance between the bad results and good results of the Forward-up map group as in UVE primed search tasks.

B. A REGRESSION MODEL TO ESTIMATE THE EFFECT OF INDIVIDUAL DIFFERENCES

The Guilford-Zimmerman Spatial Visualization (SV) and Spatial Orientation (SO) test results can be used to construct an estimation model for the Urban Virtual Environment (UVE) and the Open Ocean Virtual Environment (OOVE) test scores. If

SV and SO test scores of a participant are given, it is possible to predict UVE and OOVE test scores of this participant. In this thesis, we will construct the models to estimate the average UVE and OOVE score of a participant given his or her SV and SO scores. The regression models to estimate such relationships are provided in following sections.

1. The Regression Analysis for the North-Up Map Group

a. A First Look at the Data in order to Fit a Regression Model

The pairwise plots presented in Figure 28 provide a general idea about the underlined Regression model.

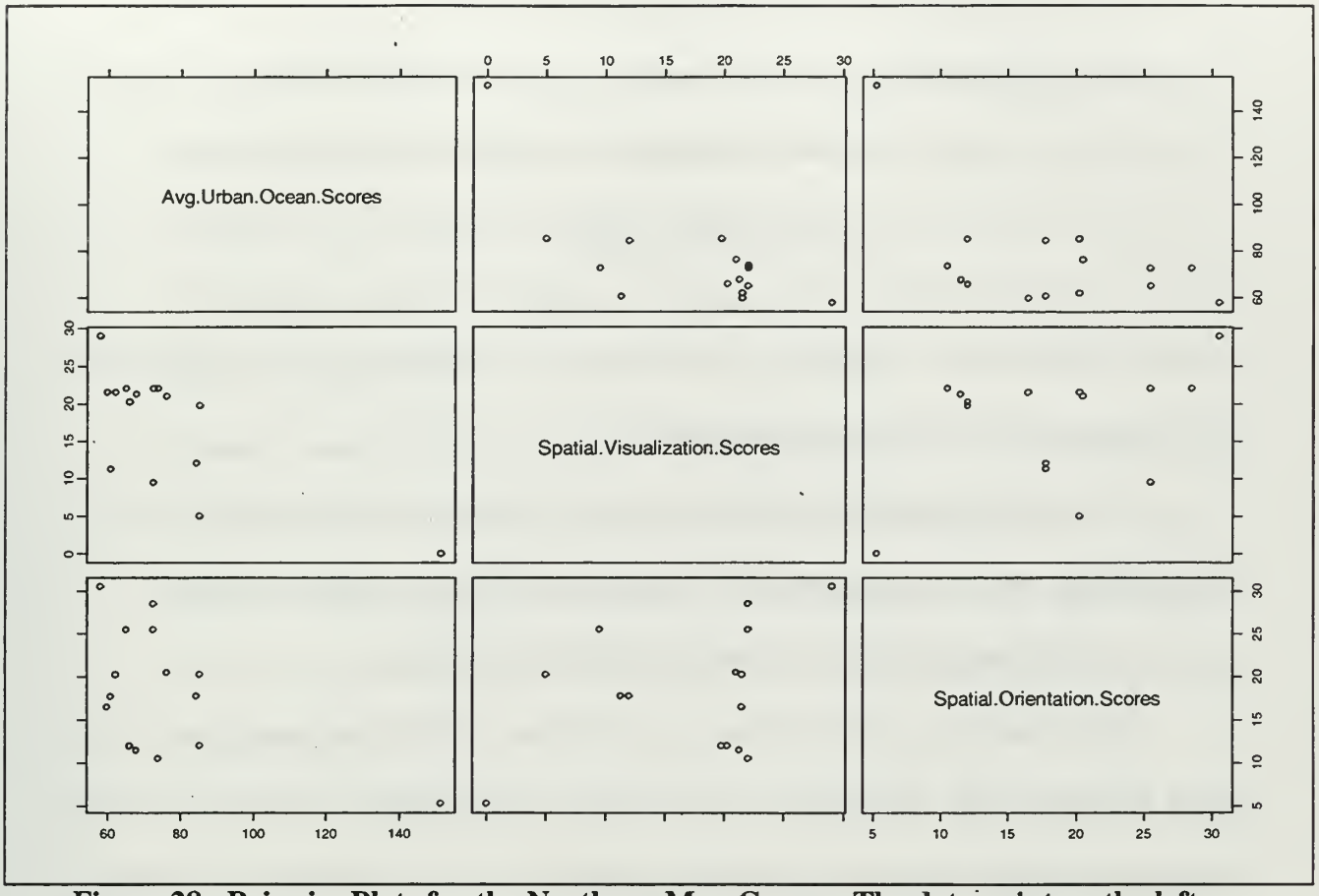

Avg.Urban.Ocean.Scores
Spatial.Visualization.Scores
Spatial.Orientation.Scores
0 5 10 15 20 25 30
60 80 100 120 140
0 5 10 15 20 25 30
60 80 100 120 140
5 10 15 20 25 30

Figure 28. Pairwise Plots for the North-up Map Group. The data point on the left-upper corner of the upper second and third plot seems to be an outlier. Excluding this data point, a Linear Regression Model can be fitted to this model

Figure 28 is a scatter plot of the data. Each circle on these plots shows a participant. Each participant can be found on these plots depending on their average urban/open ocean scores, spatial visualization scores, and spatial orientation scores. Although there exists an outlier, the plots in Figure 28 support the idea of fitting a Linear Regression Model.

b. Fitting a Multiple Linear Regression Model

As a first approach, both of the predictor parameters (SV and SO scores) will be included in our model. Hence, we will construct a Multiple Linear Regression Model.

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

Y indicates the response variable (here the Average UVE and OOVE scores), and X1 and X2 indicate the SV and SO scores, respectively.

The model will estimate β parameters, so that when we provide SV and SO scores of a participant we can estimate the average UVE and OOVE score of this individual.

c. Checking the Linear Regression Model Assumptions

Before continuing with the model, it is important to check the assumptions of the linear regression with the diagnostic plots. Along with fitting the model, it is also necessary to assess how well our model fits the data, being ready to modify the model or abandon it all together if it does not satisfactorily explain the data. Figure 29 displays the diagnostic plots that are commonly used to check the model assumptions of a linear regression model. The simplest and most informative method for assessing the fit is to look at the model graphically, using an assortment of plots. These, taken together, reveal the strengths and weaknesses of the model [MATH97]. An explanation of each plot in figure 29 is provided below.

- **The plot of the response against the fitted values.** This plot gives a good idea of how well the model has captured the broad outlines of the data (last plot in the top row in Figure 29).

- **The plot of the residuals against the fitted values**. This plot often reveals unexplained structure left in the residuals, which in a strong model should appear as nothing but noise (first plot in the top row in Figure 29).
- **Square root of absolute residuals against fitted values.** This is useful in identifying outliers and visualizing structure in the residuals (middle plot in the top row in Figure 29).
- **Normal quantile plot of residuals.** This plot provides a visual test of the assumption that the model's errors are normally distributed. If the ordered residuals cluster along the superimposed quantile-quantile line, then this plot provides strong evidence that the errors are indeed normal (first plot in the bottom row in Figure 29).
- **Residual-Fit spread plot, or r-f plot.** This plot compares the spread of the fitted values with the spread of the residuals. The ultimate goal of this plot is to show that the spread in the fitted values is much greater than that in the residuals (middle plots in the bottom row in Figure 29).
- **Cook's distance plot.** This plot is a measure of the influence of individual observations on the regression coefficients (last plot in the bottom row in Figure 29) [MATH97].

The residual plots (first and second plots in the top row) show no obvious pattern, although three observations appear to be outliers. The normal plot of the residuals (first plot in the bottom row) gives no reason to doubt that the residuals are normally distributed. The r-f plot, on the other hand (middle plots in the bottom row), shows a weakness in this model. Because the spread of the residuals is actually greater than the

spread in the original data. However, ignoring the outlier data point six will make the spread of the original data greater than the spread of the residuals (Figure 29). The

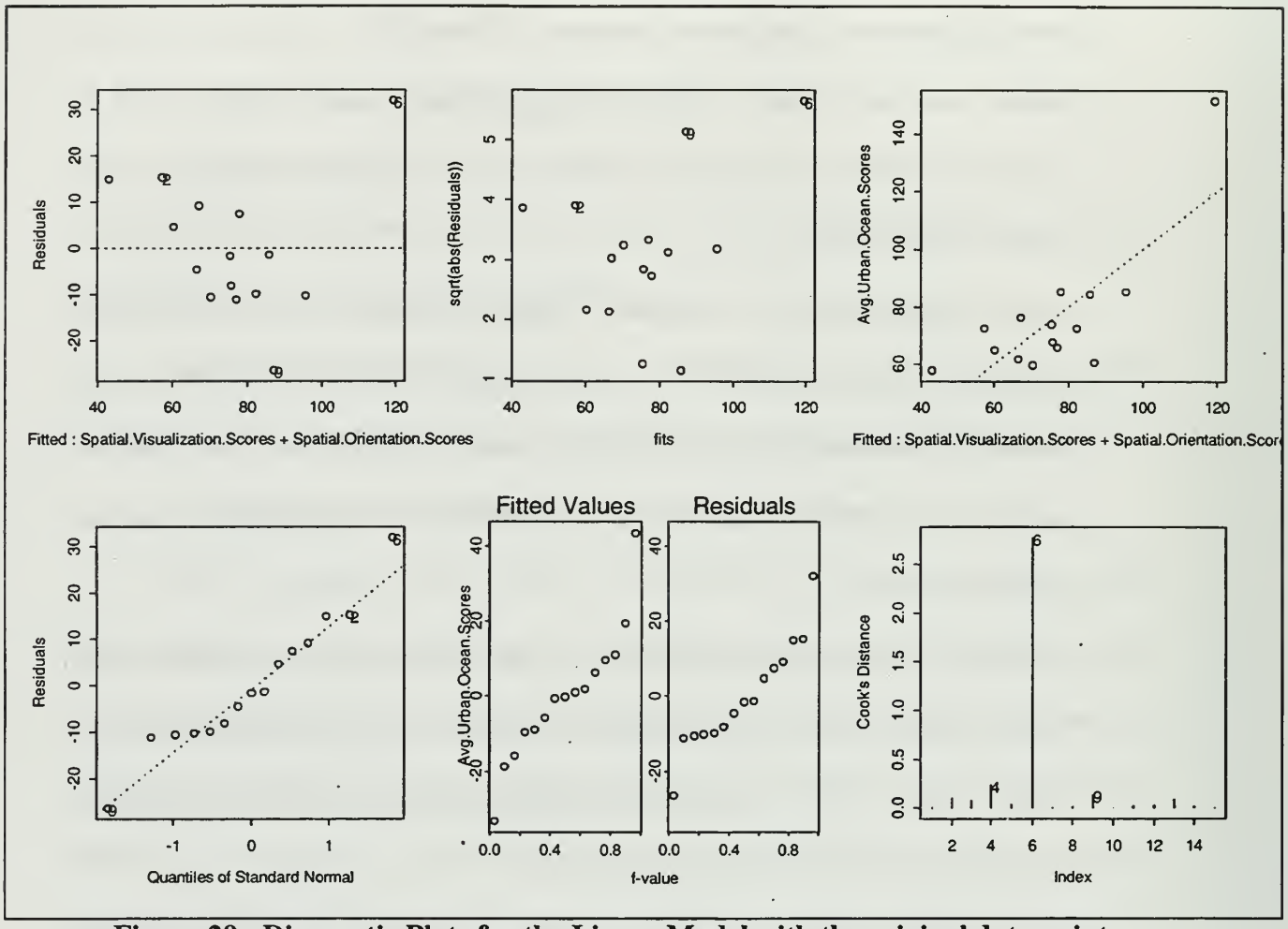


Figure 29. Diagnostic Plots for the Linear Model with the original data points .

(North-up Map Group)

Cook's distance plot (right plot in the bottom row) shows the three heavily influential observations. After only excluding data point six from the model, the data fits the model well. Why data point six is different from the other data points? Participant number six evaluated herself as a beginner with low spatial ability, which was confirmed by the Guilford-Zimmerman Spatial Visualization and Orientation scores along with the scores

of the assigned searches in two different types of virtual environment. Another reason is that she is not a naval officer. That is, her background is different than the other participants. When we look at the backgrounds of the all participants, it will be noticed that 28 participants out of 30 are naval officers. In order to reach better estimations out of this study, data point six is excluded. Figure 30 shows the new diagnostic plots for the linear regression model.

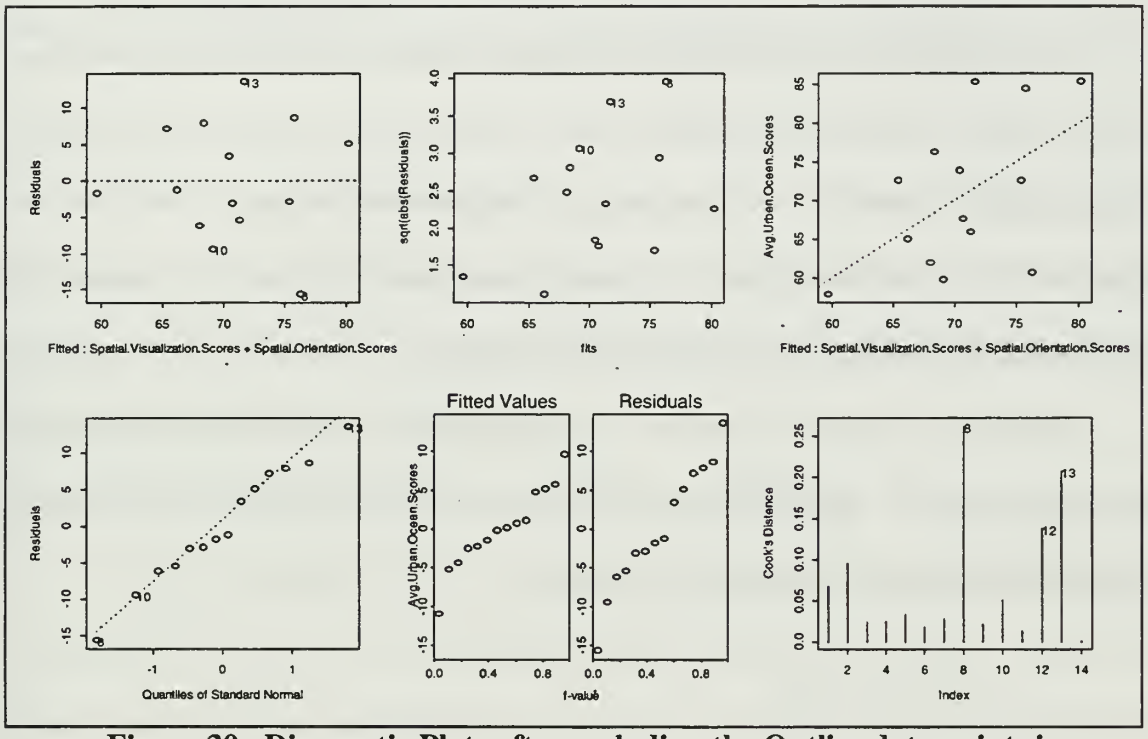


Figure 30. Diagnostic Plots after excluding the Outlier data point six (North-up Map Group)

This variable selection test recommends which parameters should be excluded from the model [MATH97].

```
> drop1(My.Mult.Reg.lm)
Single term deletions
Model:
Avg.Urban.Ocean.Scores ~ Spatial.Visualization.Scores + Spatial.Orientation.Scores

                          Df  Sum of Sq    RSS      Cp
<none>                                    834.499  1289.681
Spatial.Visualization.Scores  1  290.0451  1124.545  1427.999
 Spatial.Orientation.Scores  1  43.5697   878.069  1181.523
```

Table 7: Variable Selection Test for North-up Model

Before presenting the results of the variable selection test, it will be necessary to explain the Cp value. The Cp statistic provides a convenient criterion for determining whether a model is improved by dropping a term. If any term has a Cp statistic lower than that of the current model (shown above output on the line labeled <none>), the term with the lowest Cp statistic is dropped. If the current model has the lowest Cp statistic, the model is not improved by dropping any term [MATH97].

Since the Cp value for SO scores is less than 1289.681, then it is recommended to drop the parameter X2 and regress only SV scores on Average UVE and OOVE scores. Therefore, the new regression equation becomes:

$$\hat{Y} = \beta_0 + \beta_1 X_1$$

d. Linear Regression Results

The above Regression Model was solved in S-Plus [MATH97] and the resulting program output is shown in Table 8.

```
> summary(My.Bivariate.Reg.lm)
Call: lm(formula = Avg.Urban.Ocean.Scores ~ Spatial.Visualization.Scores)
Residuals:
   Min    1Q  Median  3Q  Max
-15.43 -4.861 -1.884  5.6 15.69
Coeffficients:
                                Value     Std. Error  t value   Pr(>|t|)
                  (Intercept)  84.6436   7.1501      11.8381   0.0000
Spatial.Visualization.Scores  -0.7595   0.3676      -2.0660   0.0611

Residual standard error: 8.554 on 12 degrees of freedom
Multiple R-Squared: 0.2624
F-statistic: 4.268 on 1 and 12 degrees of freedom, the p-value is 0.06112
Correlation of Coefficients:
                                (Intercept)
Spatial.Visualization.Scores    -0.9475
```

Table 8: The Program Output of the Single Regression Model

The above results show that there is a high negative correlation (-0.9475) between the Average UVE and OOVE scores and SV scores. Next it is necessary to determine the *coefficient of determination* which gives the proportion of the variance of Y explained by X. R-square notation can be used for this.

R-square = explained variance / total variance [LAWR92]

A linear relationship with SV scores explains about 26.24% of sample variance of average urban and open ocean virtual environment's navigation performance (time) while using a north-up virtual map orientation. If SV scores explain 26.24%, the remaining 73.76% of the variance is unexplained or residual.

Given the SV score of a user --assuming that the user has the same background with a certain education level as the participants in this experiment--, the formula, in order to calculate the average score of urban and open ocean virtual environment (assumed that the user completed the desired search tasks in both environments), will be as follows:

Y=84.6436-0.7595*X where X denotes the SV score of the user.

2. The Regression Analysis for the Forward-Up Map Groups

a. A First Look at the Data in order to Fit a Regression Model

The pairwise plots in Figure 31 suggest the use of a Linear Regression Model.

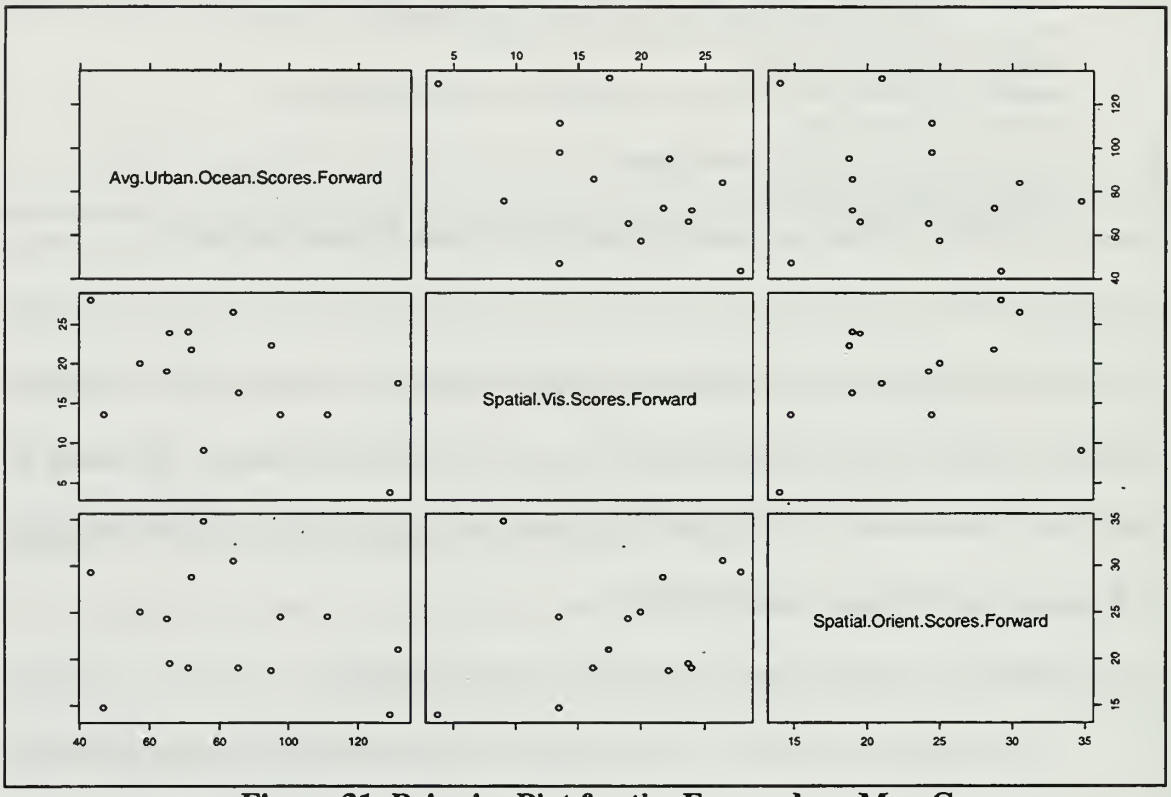


Figure 31. Pairwise Plot for the Forward-up Map Group

b. Fitting a Multiple Linear Regression Model

As a first approach, both of the predictor parameters (SV and SO scores) will be included in our model. Hence, we will construct a Multiple Linear Regression Model.

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

Y indicates the response variable (here the Average UVE and OOVE scores), and X1 and X2 indicate the SV and SO scores, respectively. The model will estimate β parameters, so

that when we provide SV and SO scores of a participant we can estimate the average UVE and OOVE score of this individual.

c. Checking the Linear Regression Model Assumptions

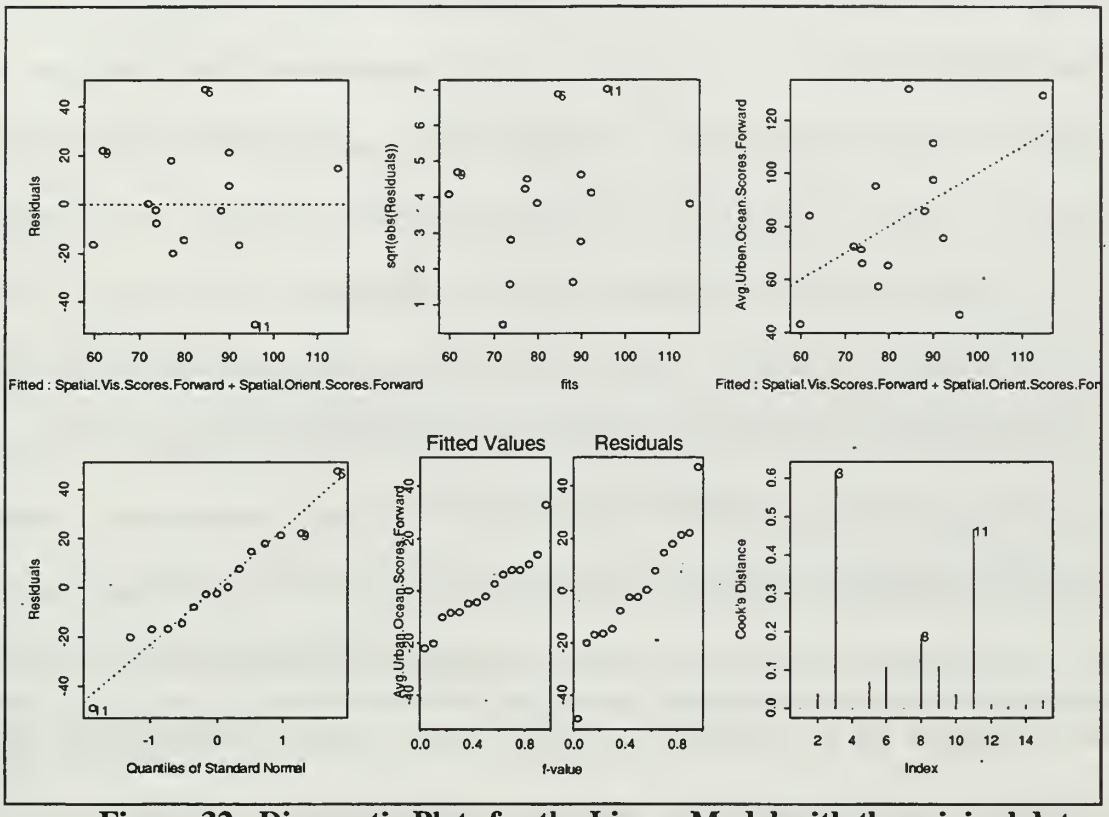


Figure 32. Diagnostic Plots for the Linear Model with the original data points (Forward-up Map Group)

The residual plots (first and second plots in the top row) show no obvious pattern, although three observations appear to be outliers. The normal plot of the residuals (first plot in the bottom row) gives no reason to doubt that the residuals are normally distributed. The r-f plot, on the other hand (middle plots in the bottom row), shows a weakness in this model because the spread of the residuals is actually greater than the spread in the original data. However, ignoring the outlier data points six and 11 will make the spread of the original data greater than the spread of the residuals (Figure 32). The

Cook's distance plot (right plot in the bottom row) shows the three heavily influential observations. After excluding the data points six and 11 from our model, the data fits the model well. The mathematical model forced us to exclude data points six (participant no 21) and 11 (participant no 26) from the linear regression model. Although participant 21 has average SV and SO scores compared to other participants in the forward-up map group, he couldn't accomplish the search tasks in either environment very well. In other words, his scores for finding the indicated targets in various searches were very high. This participant exhibited unreasonable lack of confidence in the virtual map (he somehow did not trust the virtual map) and did many unnecessary stops during the search tasks that made his scores very high. That's why this participant is an outlier. On the other hand, participant 26 did very well on search tasks in both virtual environments compared to the other participants in the forward-up map group. But his SV and SO scores are very low. He didn't spend enough time in order to understand the examples in both SV and SO tests. Participant 26 is considered an outlier because, while he received the same instructions as other participants and gave every indication of understanding the examples presented in the test booklets, he clearly did not understand as evidenced by the spatial ability test scores. Figure 33 shows the new diagnostic plots for the linear regression model after excluding these outliers.

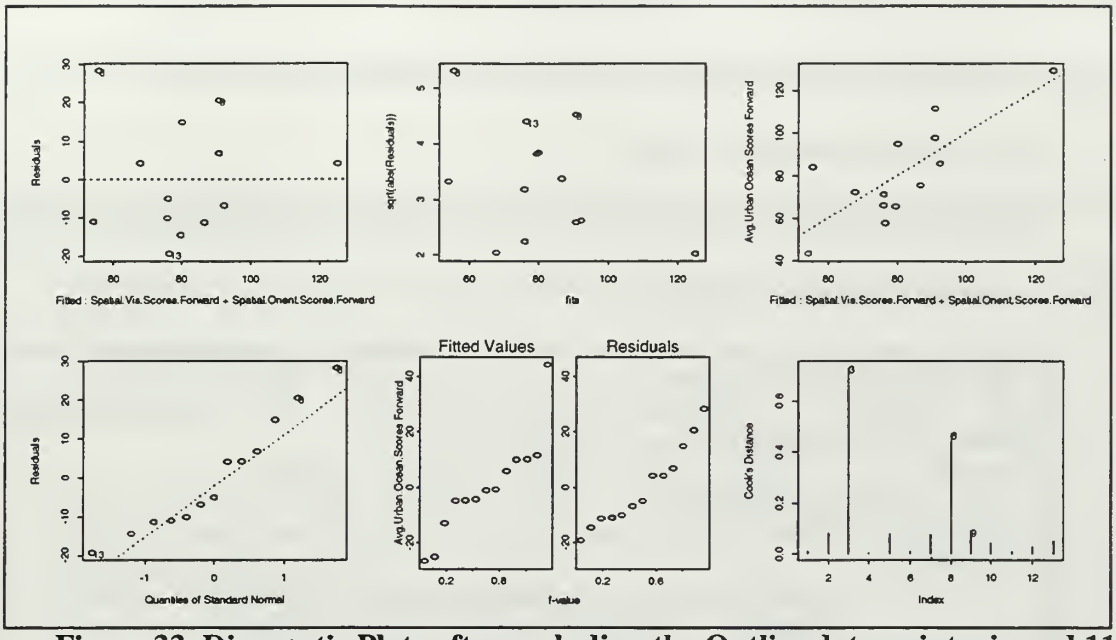


Figure 33. Diagnostic Plots after excluding the Outlier data points six and 11 (Forward-up Map Group)

The below variable selection test recommends which parameters should be excluded from the model [MATH97].

```
> drop1(My.Forward.Reg.lm)
Single term deletions
Model:
Avg.Urban.Ocean.Scores.Forward ~ Spatial.Vis.Scores.Forward + Spatial.Orient.Scores.Forward
                              Df  Sum of Sq     RSS     Cp
                    <none>                    2519.306 4030.889
  Spatial.Vis.Scores.Forward    1   2532.050  5051.355 6059.078
Spatial.Orient.Scores.Forward   1    681.968  3201.273 4208.995
```

Table 9: Variable Selection Test for Forward-up Model

Since the Cp value 4030 is less than all the others, it is recommended not to drop any parameters, meaning that both SV and SO scores will be included in our model. It is worth a reminder that SO scores of the individuals were dropped from our equation in the previous section about the north-up model. Although SO ability of an individual does not affect the performance of navigation tasks in both types of virtual environments with a

north-up map, it does affect the navigation performance with a forward-up map since the orientation of the virtual map changes depending on the participant's ERF.

d. Linear Regression Results

The above Regression model was solved in S-Plus [MATH97] and the resulting program output is shown in Table 10.

```
> summary(My.Forward.Reg.lm)
Call: lm(formula = Avg.Urban.Ocean.Scores.Forward ~ Spatial.Vis.Scores.Forward +
Spatial.Orient.Scores.Forward)
Residuals:
   Min    1Q Median   3Q  Max
 -19.35 -11.02 -5.019 6.672 28.2
Coefficients:
                              value     Std. Error  t value   Pr(>|t|)
                  (Intercept) 151.5391  21.1010     7.1816    0.0000
  Spatial.Vis.Scores.Forward   -2.0938   0.6604    -3.1703    0.0100
Spatial.Orient.Scores.Forward  -1.3210   0.8029    -1.6453    0.1309

Residual standard error: 15.87 on 10 degrees of freedom
Multiple R-Squared: 0.6077
F-statistic: 7.744 on 2 and 10 degrees of freedom, the p-value is 0.009297
Correlation of Coefficients:
                              (Intercept)  Spatial.Vis.Scores.Forward
Spatial.Vis.Scores.Forward    -0.3970
Spatial.Orient.Scores.Forward -0.7955      -0.2015
```

Table 10: The Program Output of the Multiple Regression Model

The t-test for the coefficient $\beta 2$ states that

H_0: $\beta 2=0$

H_1: $\beta 2 \neq 0$

Since the P-value (the smallest value of the level of significance (Alfa) that the null hypothesis (H_0) can be rejected) is 0.13, then with a 0.1 level of significance we fail to reject that $\beta 2=0$. However, with a 0.15 level of significance we can reject the null hypothesis.

If we become conservative and eliminate the parameter SO scores (Spatial.Orient.Scores.Forward), we obtain the following results (Table 11).

```
> summary(My.Forward.Reg.lm)

Call: lm(formula = Avg.Urban.Ocean.Scores.Forward ~ Spatial.Vis.Scores.Forward)
Residuals:
   Min    1Q Median   3Q  Max
-27.69 -14.81 -0.7608 14.04 22.46
Coefficients:
                              value     Std. Error  t value   Pr(>|t|)
                  (Intercept) 123.9220  13.7429     9.0171    0.0000
Spatial.Vis.Scores.Forward    -2.3127   0.6953      -3.3263   0.0068
Residual standard error: 17.06 on 11 degrees of freedom
Multiple R-Squared: 0.5015
F-statistic: 11.06 on 1 and 11 degrees of freedom, the p-value is 0.006756
Correlation of Coefficients:
                              (Intercept)
Spatial.Vis.Scores.Forward    -0.9389
```

Table 11: The Program Output of Confirmation to keep SO Scores

After deleting the second parameter we notice that the R-Square value decreased. Therefore, as also supported by the Variable Selection Test, keeping the second variable in the model will yield better estimations.

C. EXPLORING THE EFFECT OF TASK TYPES AND ABILITY OF THE PARTICIPANTS ON THE SUCCESS OF THE NAVIGATION

1. Urban Virtual Environment

Model: Two-Way Analysis of Variance (ANOVA) with replicates.

$$y_{i,j,k} = \mu + \alpha_i^{Task} + \alpha_j^{Ability} + \alpha_j^{Task,Ability} + \varepsilon_{i,j,k}$$

μ is the overall mean, α-task is the effect for each task type *i*, α-ability is the effect for each ability level *j* and ε is the residual corresponding to subject *k* of task type *i*, and ability level *j*.

Hypothesis Test:

Hypothesis-1

H_0: Task type has no effect on the navigation scores in UVE.

H_1: Task type has effect on the navigation scores in UVE.

Hypothesis-II

H_0: Ability level has no effect on the navigation scores in UVE.

H_1: Ability level has effect on the navigation scores in UVE.

Hypothesis-III

H_0: Task type and ability levels have no interaction effect.

H_1: Task type and ability levels have interaction effect.

or,

$$H_0 : \alpha_{Targeted}^{Task} = \alpha_{Primed}^{Task} = 0$$

$$H_0 : \alpha_{High}^{Ability} = \alpha_{Medium}^{Ability} = \alpha_{Low}^{Ability} = 0$$

$$H_0 : \alpha_{Targeted,High}^{Task,Ability} = \alpha_{Primed,High}^{Task,Ability} = \alpha_{Targeted,Medium}^{Task,Ability} = \alpha_{Primed,Medium}^{Task,Ability} = \alpha_{Targeted,Low}^{Task,Ability} = \alpha_{Primed,Low}^{Task,Ability} = 0$$

Level of Significance : α=0.05

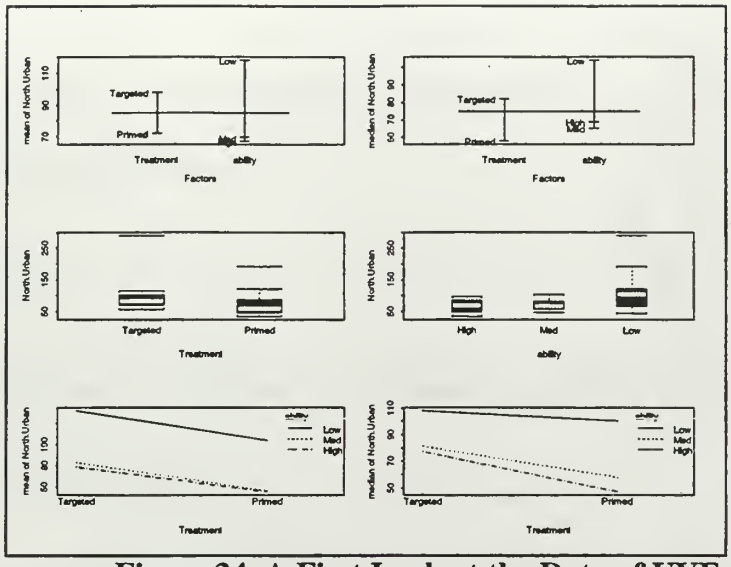


Figure 34. A First Look at the Data of UVE

The first six plots show that task type and ability level has an effect on the scores, and the last two plots show that there is no interaction effect due to task type and ability level.

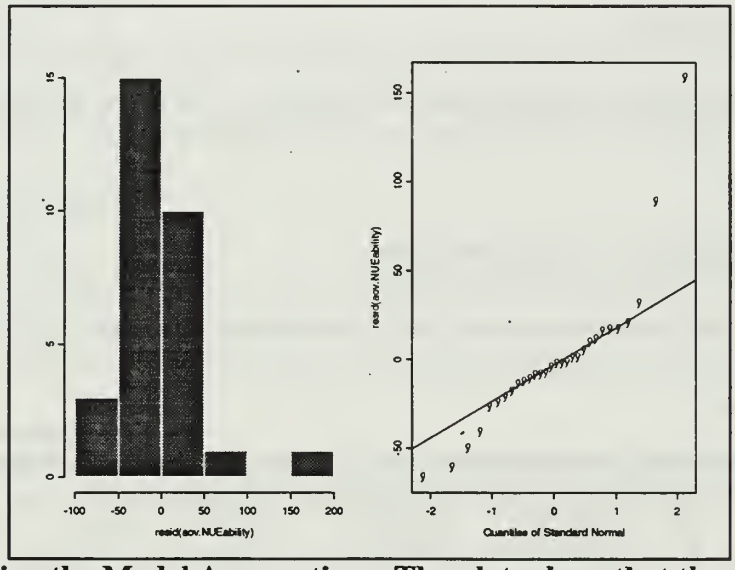


Figure 35. Checking the Model Assumptions. The plots show that the residuals are not normally distributed

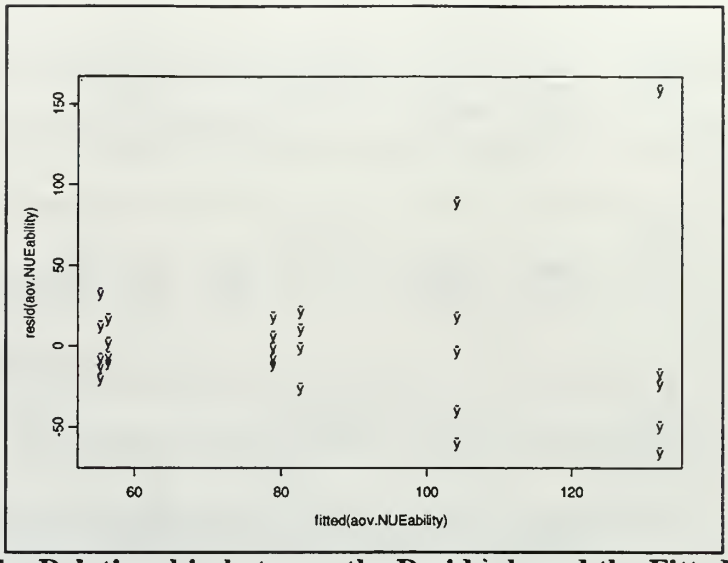


Figure 36. The Relationship between the Residuals and the Fitted Values

The result, displayed in the Figure 36, clearly reveals a strong relationship between the residuals and the fitted values. The variability of the residuals increases with increasing fitted values.

Since the model assumptions do not hold, a variance stabilizing transformation would be useful.

Variance Stabilization Transformation:

The model assumptions hold with a reciprocal transformation of the data.

Anova Results:

> summary(aov(1/North.Urban~ability*Treatment,NUEability.df))

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
ability	2	0.0001627899	0.0000813950	3.438380	0.0486356
Task	1	0.0002001882	0.0002001882	8.456581	0.0077133
ability:Task	2	0.0000268305	0.0000134152	0.566702	0.5748030
Residuals	24	0.0005681394	0.0000236725		

Table 12. The Anova Results for the UVE

P-values for task type and ability level are less than the level of significance. However, the p-value for the interaction is greater than the level of significance.

Therefore, we can reject the null hypothesis for "Hypothesis Test I" and "Hypothesis Test II", but not for "Hypothesis Test III".

Conclusion:

With a 0.05 level of significance we conclude that task type and ability level have an effect on the UVE scores.

2. **Open Ocean Virtual Environment**

Model: Two-Way Analysis of Variance (ANOVA) with replicates.

Hypothesis Test :

Hypothesis-1

H_0: Task type has no effect on the navigation scores in OOVE.

H_1: Task type has effect on the navigation scores in OOVE.

Hypothesis-II

H_0: Ability level has no effect on the navigation scores in OOVE.

H_1: Ability level has effect on the navigation scores in OOVE.

Hypothesis-II1

H_0: Task type and ability level have no interaction effect.

H_1 : Task type and ability level have interaction effect.

Or,

$$H_0 : \alpha^{Task}_{Targeted} = \alpha^{Task}_{Primed} = 0$$

$$H_0 : \alpha^{Ability}_{High} = \alpha^{Ability}_{Medium} = \alpha^{Ability}_{Low} = 0$$

$$H_0 : \alpha^{Task,Ability}_{Targeted,High} = \alpha^{Task,Ability}_{Primed,High} = \alpha^{Task,Ability}_{Targeted,Medium} = \alpha^{Task,Ability}_{Primed,Medium} = \alpha^{Task,Ability}_{Targeted,Low} = \alpha^{Task,Ability}_{Primed,Low} = 0$$

Level of Significance : α=0.05

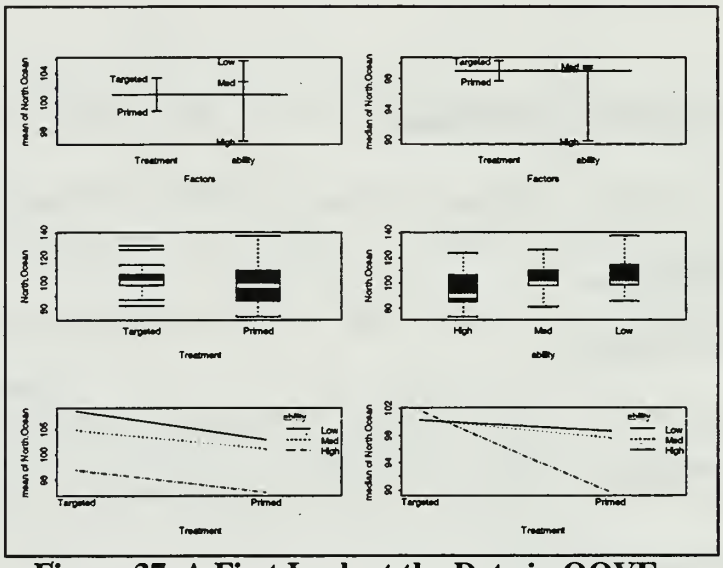


Figure 37. A First Look at the Data in OOVE

The means and medians are close to each other. The last plot shows that there is an interaction effect due to task type and ability level.

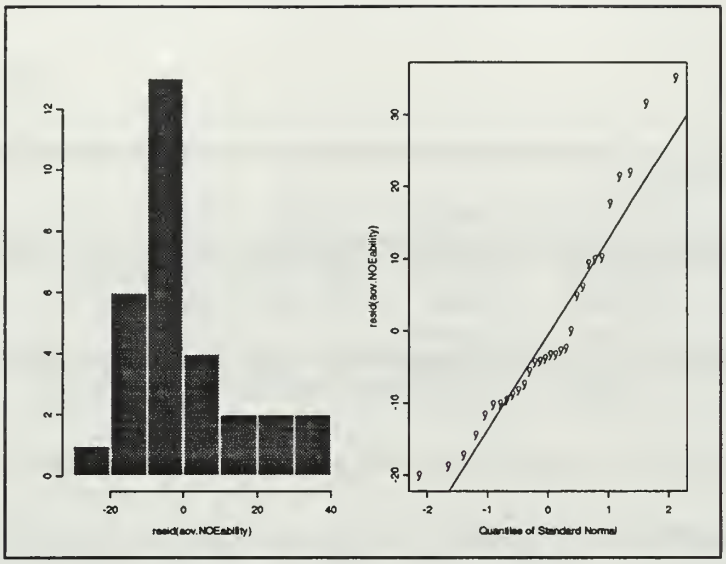


Figure 38. Checking the Model Assumptions. The plots show that the residuals are normally distributed

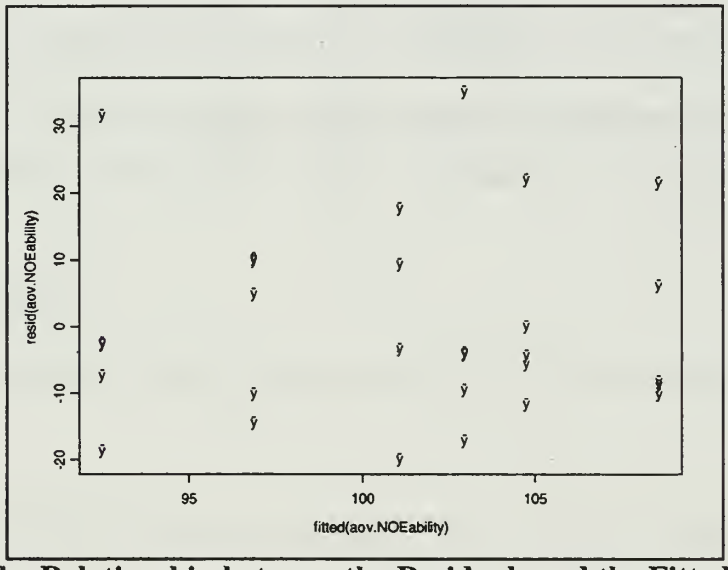


Figure 39. The Relationship between the Residuals and the Fitted Values

The result, displayed in the Figure 39, doesn't reveal a relationship between the residuals and the fitted values.

Both Figures 38 and 39 support the model assumptions. Therefore, we can apply our model.

Anova Results :

> summary(aov.NOEability)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
ability	2	663.947	331.9734	1.362166	0.2752025
Task	1	157.140	157.1399	0.644782	0.4298652
ability:Task	2	5.118	2.5590	0.010500	0.9895594
Residuals	24	5849.037	243.7099		

Table 13. The Anova Results for the OOVE

P-values for task type, ability level, and interaction between them are greater than the level of significance. Therefore, we can not reject the null hypothesis for all three tests.

Conclusion:

With a 0.25 level of significance we can not conclude that task type and ability level have an effect on the open ocean virtual environment scores.

D. EFFECT OF MAP TYPE ON THE ERRORS MADE IN UVE AND OOVE

Participant No	Errors in UVE	Errors in OOVE	Total Errors	Participant No	Errors in UVE	Errors in OOVE	Total Errors
1	23	7	30	16	13	5	18
2	9	4	13	17	13	7	20
3	8	9	17	18	5	5	10
4	1	0	1	19	2	14	16
5	8	6	14	20	2	3	5
6	40	14	54	21	16	7	23
7	10	4	14	22	6	11	17
8	25	7	32	23	13	10	23
9	16	10	26	24	3	0	3
10	10	8	18	25	8	5	13
11	9	7	16	26	7	5	12
12	6	5	11	27	8	4	12
13	12	6	18	28	11	6	17
14	13	10	23	29	3	7	10
15	8	7	15	30	7	7	14

Table 14. (A) Errors in North-up Map (B) Errors in Forward-up Map

Hypothesis Test:

Null Hypothesis H_0: Map type has no effect on the errors made in UVE and OOVE.

Alternative Hypothesis H_1: Map type has effect on the errors made in UVE and OOVE.

Or,

$$H_0 : \mu_{north} - \mu_{forward} = 0$$

$$H_1 : \mu_{north} - \mu_{forward} > 0$$

Level of Significance: 0.1

Statistical Test: Wilcox Rank Sum Non-parametric Test is applied to the model.

```
Wilcoxon rank-sum test
data:  x: north, and y: forward
rank-sum normal statistic with correction Z = 1.4965, p-value = 0.0673
alternative hypothesis: true mu is greater than 0
```

Table 15: The S-Plus Output of Wilcox Rank Sum Non-parametric Test

Since the p-value is 0.0673, which is less than the level of significance, we reject the null hypothesis. Wilcox Rank Sum is a Non-parametric Test. Once a non-parametric test results rejecting the null hypothesis, then it is not required to apply a parametric test.

Conclusion: With 0.1 level of significance, Wilcox Rank Sum Non-parametric Test supports that the mean of the participants who used north-up map orientation during the experiment is greater than the mean for the ones who used forward-up map orientation during the experiment. That is, participants with a north-up map orientation had more errors than the participants with a forward-up map orientation.

V. CONCLUSIONS

This chapter discusses and summarizes the results of chapter IV. The figures in this chapter are examples from the experimental data, chosen as typical of their group. In the urban virtual environment, a stream of white dots indicates the search trail. In the ocean environment, it is indicated by a thick line.

A. EFFECTS OF MAP ORIENTATION

The forward-up map orientation is superior to the north-up map orientation for targeted search tasks in the UVE with regard to time and errors (Figure 40). Targeted searches are viewed as purely in the ERF, and consequently, only ERF information is required. The forward-up map best supplies this because it requires less mental rotation. As seen in Figure 41, the forward-up track is far more direct than the north-up track. The north-up map tends to be susceptible to "wrong turns" where a user goes left when they mean to go right due to an error in transforming the ERF to the WRF on the map.

This result carries over from dense environments to sparse environments. The forward-up map orientation is better than the north-up map orientation for targeted search tasks in the OOVE (Figure 42).

With a 0.1 level of significance, we cannot conclude that one map orientation is better than the other for primed search tasks. However, further analysis shows that participants in the forward-up map group with high spatial abilities perform better than participants in the north-up group, also with high spatial abilities.

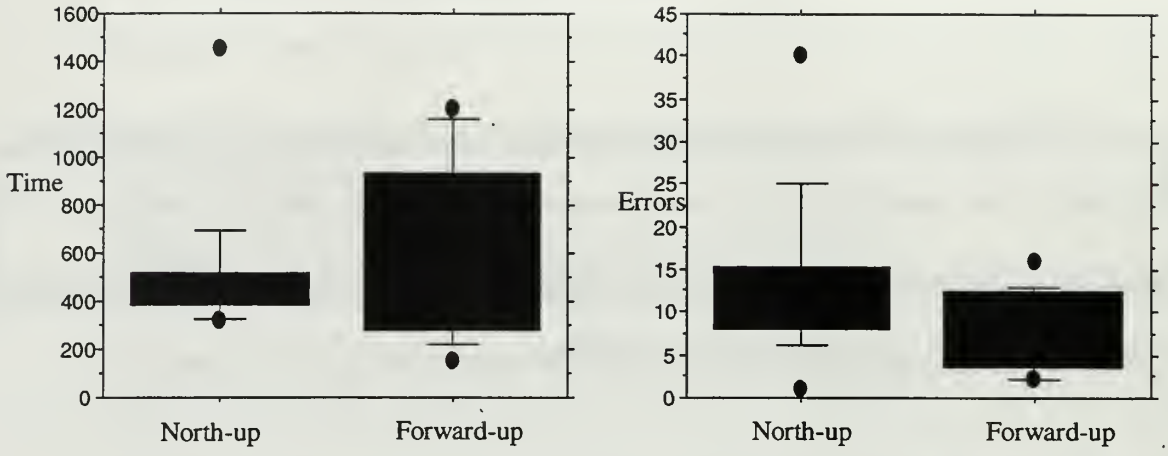


Figure 40. Time and Errors in Targeted Searches in the Forward-up and North-up Treatments in UVE

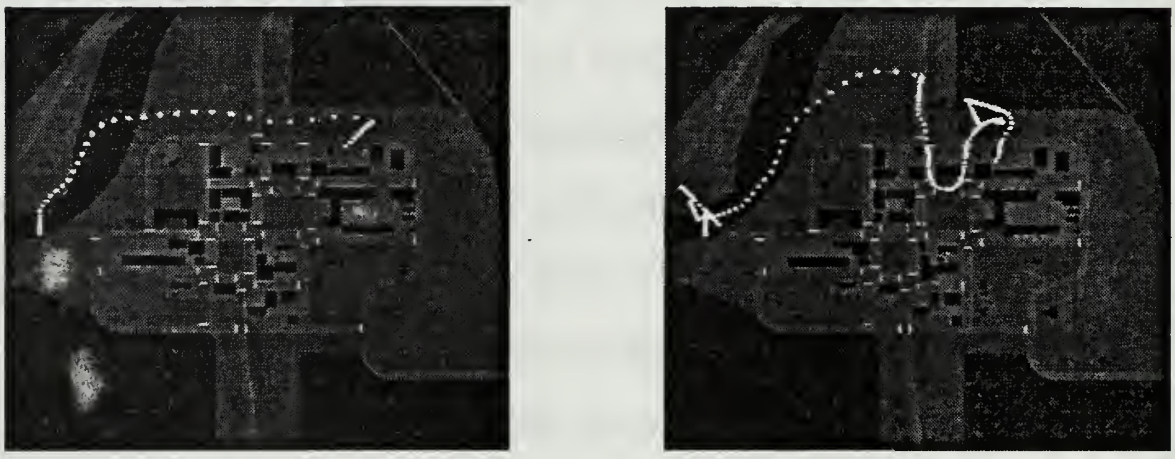


Figure 41. Targeted Searches in Forward-up (Left) and North-up Map (Right) Treatments

Conversely, participants with low spatial abilities in the forward-up map group perform worse than participants in the north-up map group, also with low spatial abilities. This effect resulted in a balance between the scores of both groups. What seems to happen is that high spatial individuals treat primed searches like targeted searches

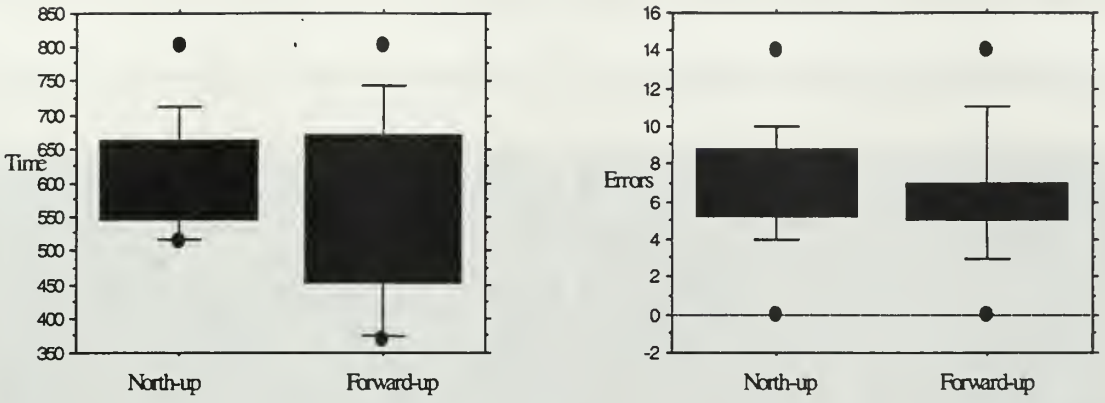


Figure 42. Time and Errors in Targeted Searches in the Forward-up and North-up Map Treatments in OOVE

because they have few difficulties in transforming the ERF to the WRF and vice versa. Individuals with low spatial abilities, however, have greater difficulties in transforming the ERF to the WRF, and consequently often treat the primed searches like naïve searches, e.g. their strategy involves performing an exhaustive search because they often cannot identify the location on the map where they need to go. This is evident in their search tracks where we often see them crossing their path and re-searching areas under the forward-up condition, versus the north-up condition, where we see relatively coherent strategies and better performance (Figure 43).

The naïve search seems to show a similar effect, but not at significant levels. The forward-up map (Figure 44 (Left)) illustrates an unorganized exhaustive search, typical of this treatment. Since the map seems to "turn" in front of the user (actually it is the user turning about the map), it is difficult to develop a reasonable strategy to cover the entire environment in an efficient manner. The north-up map, however, (Figure 44 (Right)) illustrates a relatively efficient search. This participant happens to have been fairly lucky in finding the target after searching only two blocks of the town, but it is safe to say that

had the target been somewhere else, it would have been located in short order based on the "back and forth" method used here.

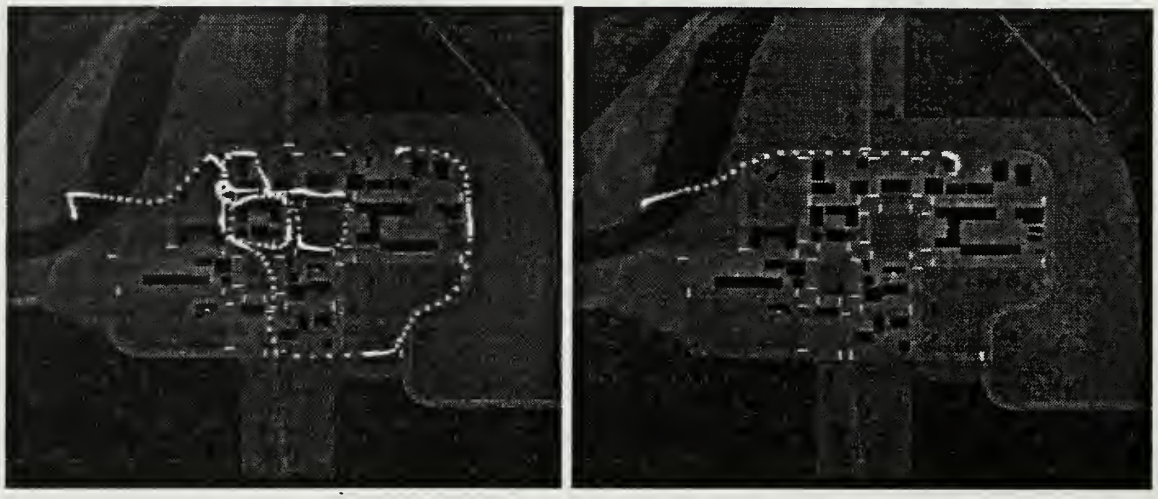


Figure 43. Primed Searches of Low spatial participants in Forward-up (Left) and North-up Map Treatment (Right)

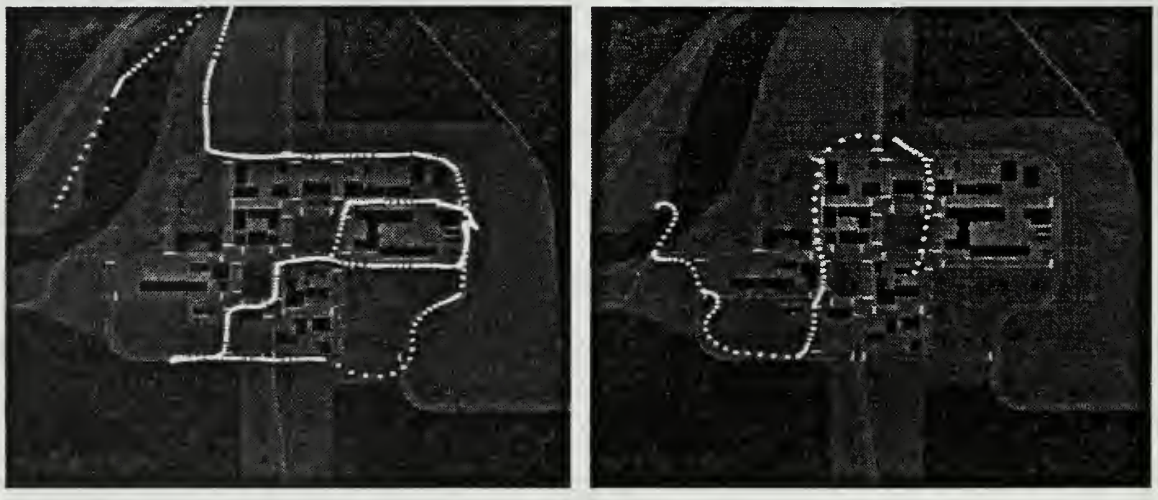


Figure 44. A Naïve Search in Forward-up (Left) and North-up (Right) Map Treatment

These same results are also true of the OOVE. With a 0.1 level of significance, we cannot conclude that one map orientation is better than the other for primed search tasks. However, the same difference with respect to high and low spatial individuals applies here. It was noticed that the forward-up map (Figure 45 (Left)) tended to exhibit slightly poorer task execution than the north-up map (Figure 45 (Right)). In this particular case, the forward-up map shows an error around the target in the lower left corner where the north-up map is direct and accurate.

Figure 45. A Primed Search Task in the Forward-up (Left) and North-up (Right) Map Treatment

B. EFFECTS OF INDIVIDUAL DIFFERENCES

The results in chapter IV indicate a difference in performance in the north-up map condition based on spatial visualization (SV) ability. For the UVE, with a 0.05 level of significance, we conclude that participants' spatial ability has an effect on performance for all navigational tasks. As seen in Figure 46 (Left), the low spatial individual has great difficulty transforming the ERF to the WRF and consequently makes many errors in locating the target. The high spatial individual (Figure 46 (Right)) exhibits none of this behavior.

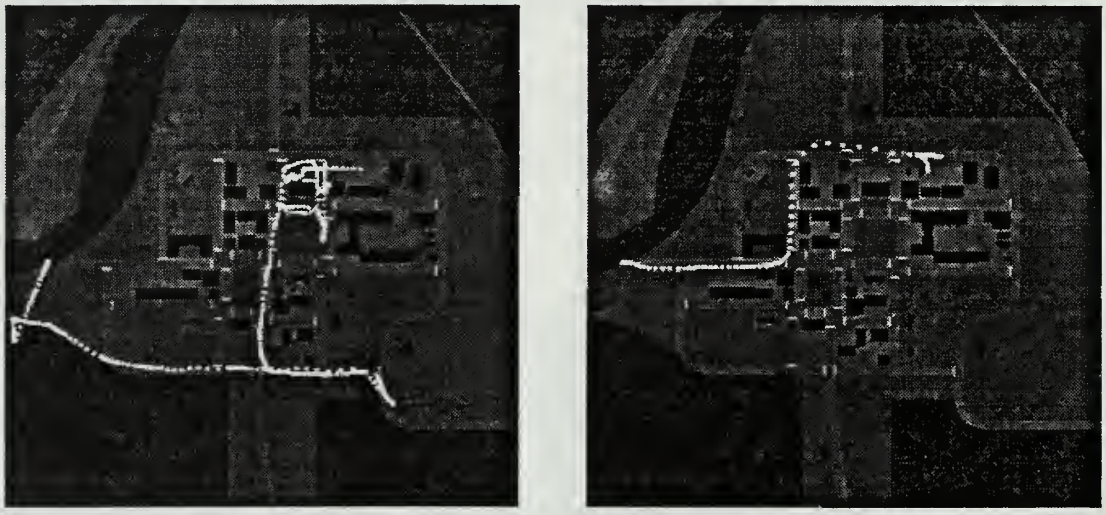


Figure 46. A Primed Search in the North-up Map Treatments of a Low SV (Left) and a High SV (Right) Participant

However, for the OOVE, this effect is not as great. It cannot be definitively concluded that spatial ability has an effect on navigational performance. Nevertheless, it would not be wrong to indicate that a sample population of other than all technical individuals would have proven significant in this case. These results also indicate a

difference in performance in the forward-up condition in both environments based on SV and SO scores (Figure 47). This is a stronger effect, being consistent across both types of environment. As stated earlier, low spatial participants tend to approach both the primed and naïve searches as exhaustive searches, thus greatly lowering performance. A WRF perspective (e.g. the north-up map) best serves exhaustive searches because more than simple ERF directional information is required. This would imply that for the north-up condition, low spatial participants struggled with the first three targeted searches, but then improved over the rest of the trial. However, low spatial participants in the forward-up condition would have done well on the first three targeted searches and then struggled with the remaining four searches. This is in fact why the effect is stronger in this experiment. If the tasks had been divided evenly between ERF and WRF tasks, it might be true that the effect would have been equally strong across map orientation conditions and environment types.

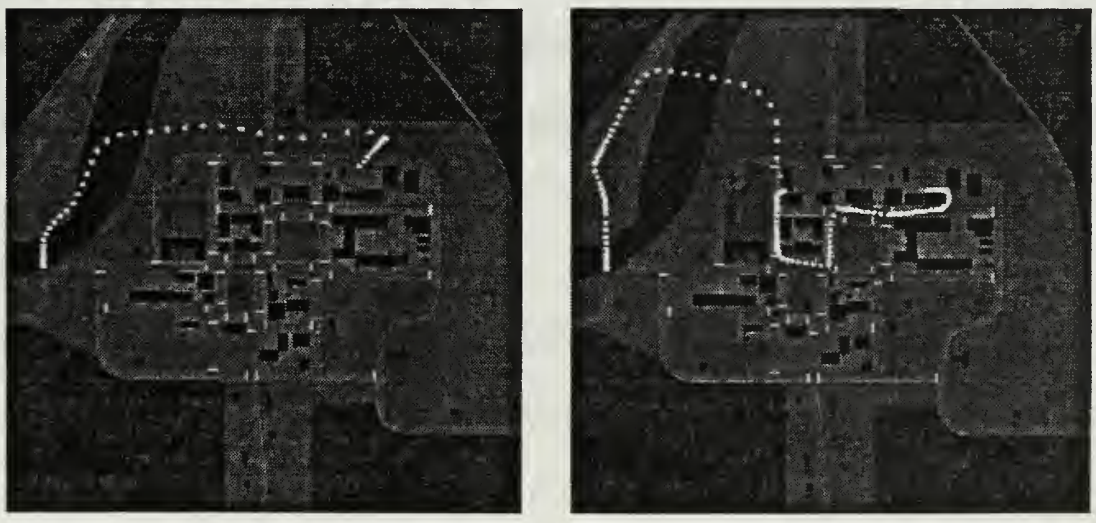


Figure 47. A Primed Search in the Forward-up Treatments of a High (Left) and a Low (Right) SV/SO Participant

C. EFFECTS OF VIRTUAL ENVIRONMENT TYPE

It was expected from the onset that navigating the OOVE would be significantly more difficult than navigating the UVE. It was thought that having cues to navigate by must be better than having none, which is almost the case in the sparse ocean environment. Surely, having many cues by which to triangulate and perform mental rotations must be easier than not having those cues at all. However, the abundance of cues in the UVE seems to be exactly what may have caused problems on some search tasks. In particular, the Performer town environment is somewhat symmetrical. Consequently, many participants had difficulty remembering where targets had been found in order to execute primed searches in the forward-up treatment. Also, even in cases where these cues were a benefit, these same cues are a cause of visual obstruction and they inhibited movement. Navigation performance, error rates, post-trial comments of participants, and direct observations indicate that navigating in the OOVE may actually be easier in some cases regardless of map orientation. The OOVE is very simple. Even participants with less spatial ability completed the tasks with about the same level of proficiency in the OOVE as compared to the UVE.

D. CONCLUSIONS

The three basic principles of virtual map representation identified in this thesis are:

- For ERF tasks such as targeted searches or primed searches, a forward-up map is preferable to a north-up map. It is important to note that a primed search can be either an ERF task or WRF task depending on the individual's spatial

ability. For individuals with high spatial ability, a primed search is classified as an ERF task.

- For WRF tasks such as primed or naïve searches, a north-up map is preferable to a forward-up map. For individuals with low spatial ability, a primed search is classified as a WRF task.
- Under almost every possible condition, individuals with high spatial abilities will be able to use either type of map better than individuals with low spatial abilities.

Furthermore, it was found that these principles apply across types of environment with vastly different spatial characteristics, but sparse environments seem to exhibit less of a performance difference than dense environments. Virtual environment designers should make virtual map decisions by carefully weighing the priorities of navigation task versus the spatial ability of their users.

Maps that adhere to these principles and that dynamically show the viewpoint position on the map simplify ERF to WRF perspective transformations that are required for map use. The results of this thesis suggest that perspective transformation (ERF to WRF and vice versa) may be a partially trainable skill. While it is not suggested that individuals with low spatial ability can be trained to be comparable to those with high spatial ability, they may be able to raise their general level of performance with repeated exposure to perspective transformation tasks. This supposition shouldn't be taken too far based on this data alone, however.

E. FUTURE WORK

There seemed to be several problems in using the forward-up maps with regard to losing track of where "north" was. It may be possible to significantly raise performance in the forward-up group simply by marking one side of the map in some obvious way. It has been previously shown that a global direction cue, such as a sun, can have a pronounced effect on performance and strategy [SIBE93]. This may also be true as applied to maps.

Future research in this area must address the issue of game playing experience by participants. The fact that some participants have played possibly hundreds of hours on games that use maps in different configurations with YAH indicators must have an effect on task performance, and consequently, experimental data. How this exposure or training effect interacts with natural spatial abilities is unknown at this time but warrants further study.

For tasks requiring spatial knowledge acquisition of a specific space, prolonged exposure to a VE with (and without) a virtual map display will allow us to determine if an orientation-independent cognitive map can be constructed as effectively in a virtual environment as it is in the real world allowing people to familiarize themselves with places they have never before visited.

APPENDIX A: DESCRIPTIVE STATISTICS

This appendix discusses:

- The paper-based Self-Ability Evaluation (SAE), Santa Barbara Sense-of-Direction Scale (SBSODS), Guilford-Zimmerman Spatial Visualization (SV), and Guilford-Zimmerman Spatial Orientation (SO) tests.
- The computer-based test scores depending on the assigned navigation search task in terms of time and errors.

Only descriptive statistics are shown here. Chapter IV Analysis will relate to these data to navigation performance.

A. SELF-ABILITY EVALUATION (SAE) AND SANTA BARBARA SENSE-OF-DIRECTION SCALE (SBSODS) RESULTS OF NORTH-UP MAP GROUP

The Self-Ability Evaluation is a qualitative self-analysis of an individual's navigational ability. It provides a participant with general limits from which to appraise his perceived navigation aptitude. The left end of the scale is valued at 0.00 and the right end of the scale is valued at 1.00. Values measured from 0.00 to 0.33 are assessed as beginner with low navigation ability. From 0.33 to 0.66 is ranked as intermediate navigator with medium navigation ability. Values from 0.66 to 1.00 are evaluated as experts with high navigation ability. For north-up map group, two participants evaluated themselves as beginners with low navigation ability, nine participants evaluated themselves as intermediate with medium navigation ability, and four participants

evaluated themselves as experts with high navigation ability out of total fifteen participants (Table 16).

Participant No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg	Std. Dev.
SBSODS Score	2.8	2.4	2.46	2.46	2.6	6.53	1.66	2.26	4.26	2.33	4.6	2.53	4.8	2.33	4.26	3.22	1.80
SAE	med	med	med	high	med	low	high	med	med	high	med	med	low	high	med		

Table 16: SBSODS and SAE Scores of North-up Map Group

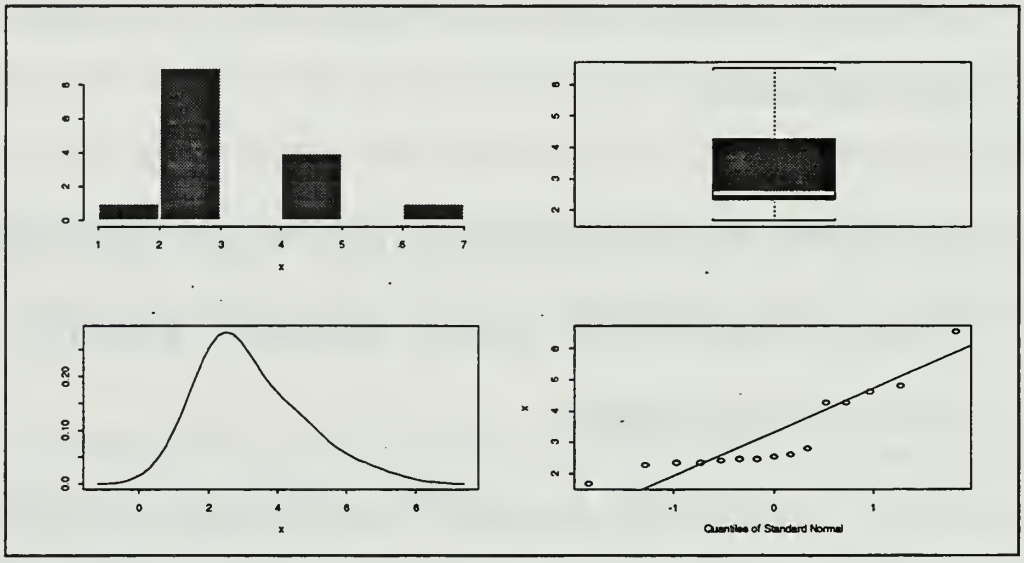


Figure 48. Exploratory Data Analysis (EDA) Plots of SBSODS Scores of North-up Map Group

The Santa Barbara Sense-of-Direction Scale is a quantitative self-evaluation of navigational ability. The University of California at Santa Barbara developed the scale. An individual's score is calculated by reversing the values of questions 2, 6, 8, 10, 11,12,13, and 15. For example, if the participant answered the question number eight as "2", the question is given a numerical value of "6" during evaluation. Once the values of these questions are reversed, sum the value of each question and divide the total value by the number of questions answered. The lower the resulting score, the more confidant an

individual is in their navigational abilities. The University of California at Santa Barbara has calculated the scale's mean score to be 3.54 with a standard deviation of 1.03. For the participants of north-up map group, the mean score was 3.22 with a standard deviation of 1.8 (Table 16, Figure 48).

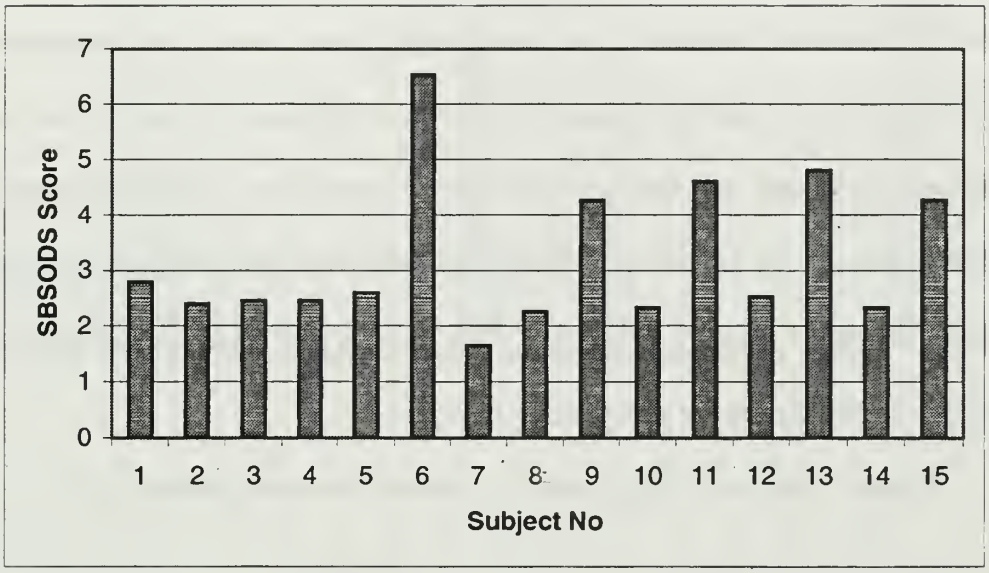


Figure 49. Graphical Representation of SBSODS Scores

B. GUILFORD-ZIMMERMAN SPATIAL VISUALIZATION (SV) AND SPATIAL ORIENTATION (SO) RESULTS OF NORTH-UP MAP GROUP

Spatial ability is usually measured by psychometric tests. A problem with these tests is that they present problems using small-scale objects, whereas most of our interaction with the real world is in large-scale spaces. Small-scale refers to an object or environment that can be seen in its entirety from at least one viewpoint. Large-scale spaces must be learned from sequential exposures. It was not until recently that one of

these spatial ability tests, the Guilford-Zimmerman Spatial Orientation Test, was shown to predict performance in a large-scale space. At present, the other psychometric tests measuring spatial relations and visualization have not been validated for large-scale navigation performance [SATA95].

Before giving the Spatial Visualization test to the participants, all of them were given unlimited time for examining the example questions and given explanations to any questions they had. Each participant was given a 10-minute period for the test after the participant indicated that he/she was ready. Scores were calculated according to the following formula as instructed in **Guilford-Zimmerman Manual of Instructions and Interpretations** (Figure 51, Table 17). The genders and backgrounds of participants of the north-up map group are presented in Figure 50.

Score = Number of right answers - (number of wrong answers / 4)

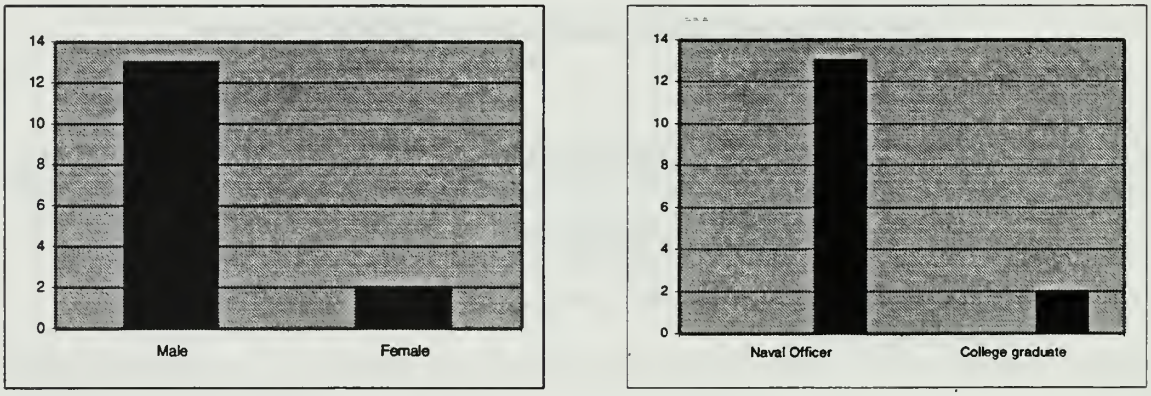


Figure 50. Gender and Background of Participants of North-up Map Group

Guilford-Zimmerman Manual of Instructions and Interpretations has calculated the mean score of spatial visualization test to be 27.93 with a standard deviation of 14.26 for college men, 16.3 and 11.37 for college women.

SPATIAL VISUALIZATION TEST SCORES			
Participant No	Right No	Wrong No	Score
1	14	8	12
2	23	4	22
3	12	10	9.5
4	30	4	29
5	21	3	20.25
6	5	20	0
7	22	2	21.5
8	22	4	21
9	13	7	11.25
10	24	8	22
11	22	2	21.5
12	23	7	21.25
13	9	16	5
14	21	5	19.75
15	24	8	22
Average	**19**	**7.2**	**17.2**
Std.dev.	**6.78**	**5.06**	**7.83**

Table 17: Spatial Visualization Scores of North-up Map Group

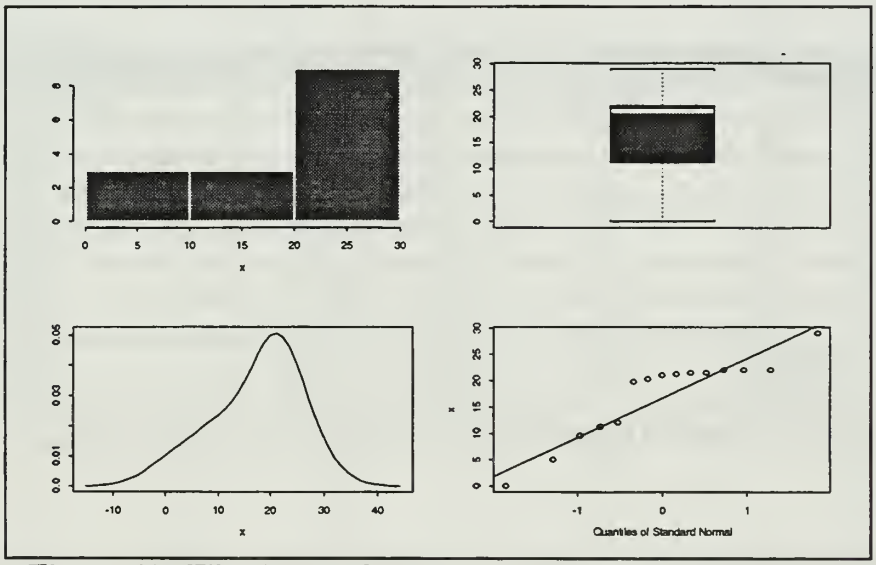


Figure 51. EDA Plots of Spatial Visualization Test Scores of North-up Map Group

Before giving the Spatial Orientation test to the participants, all of them were given unlimited time for examining the example questions and given explanations to any questions they had. Each participant was given a 10-minute period for the test after the participant indicated that he/she was ready. Scores were calculated according to the following formula as instructed in **Guilford-Zimmerman Manual of Instructions and Interpretations** (Figure 52, Table 18).

Score = Number of right answers - (number of wrong answers / 4)

SPATIAL ORIENTATION TEST SCORES			
Participant No	Right No	Wrong No	Score
1	19	5	17.75
2	29	2	28.5
3	28	10	25.5
4	32	6	30.5
5	13	4	12
6	9	15	5.25
7	21	2	20.25
8	20	3	19.25
9	19	5	17.75
10	12	6	10.5
11	18	6	16.5
12	14	10	11.5
13	21	3	20.25
14	15	12	12
15	26	2	25.5
Average	**19.73**	**6.06**	**18.2**
Std.dev.	**6.69**	**3.97**	**7.2**

Table 18: Spatial Orientation Scores of North-up Map Group

Guilford-Zimmerman Manual of Instructions and Interpretations has calculated the mean score of spatial orientation test to be 20.5 with a standard deviation of 10.32 for college men, 12.62 and 8.67 for college women.

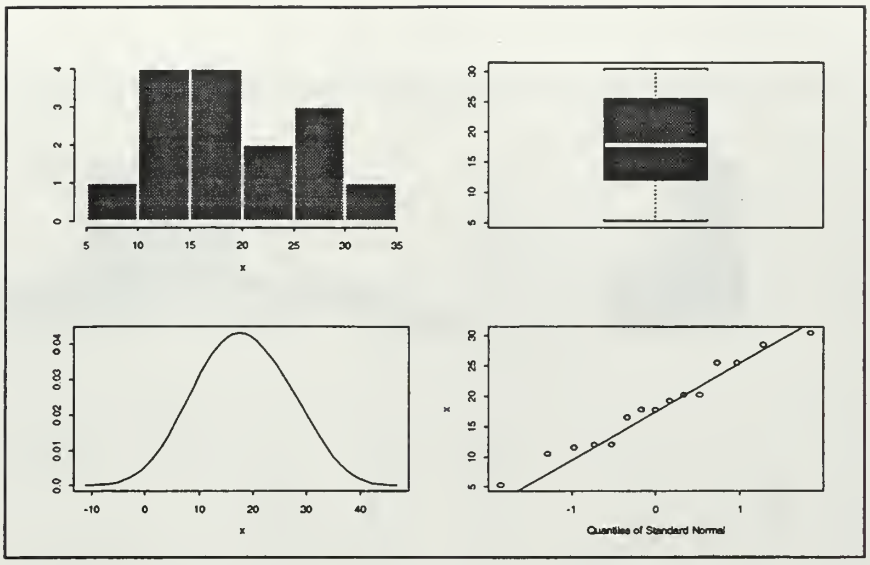


Figure 52. EDA Plots of Spatial Orientation Test Scores of North-up Map Group

C. NORTH-UP MAP GROUP URBAN VIRTUAL ENVIRONMENT (UVE) TARGETED, PRIMED, AND NAÏVE SEARCH RESULTS

TARGETE D SEARCH			
Participant No	RED	GREEN	BLUE
1	87	76	161
2	153	39	39
3	97	95	54
4	141	47	24
5	129	44	70
6	576	233	62
7	119	60	73
8	99	74	104
9	94	47	56
10	128	43	29
11	84	42	42
12	120	50	72
13	213	72	58
14	156	100	54
15	203	39	46
Average	**159.93**	**70.73**	**62.93**
Std.dev.	**121.46**	**49.14**	**33.52**

Table 19: Targeted Search Scores of North-up Map Group in UVE

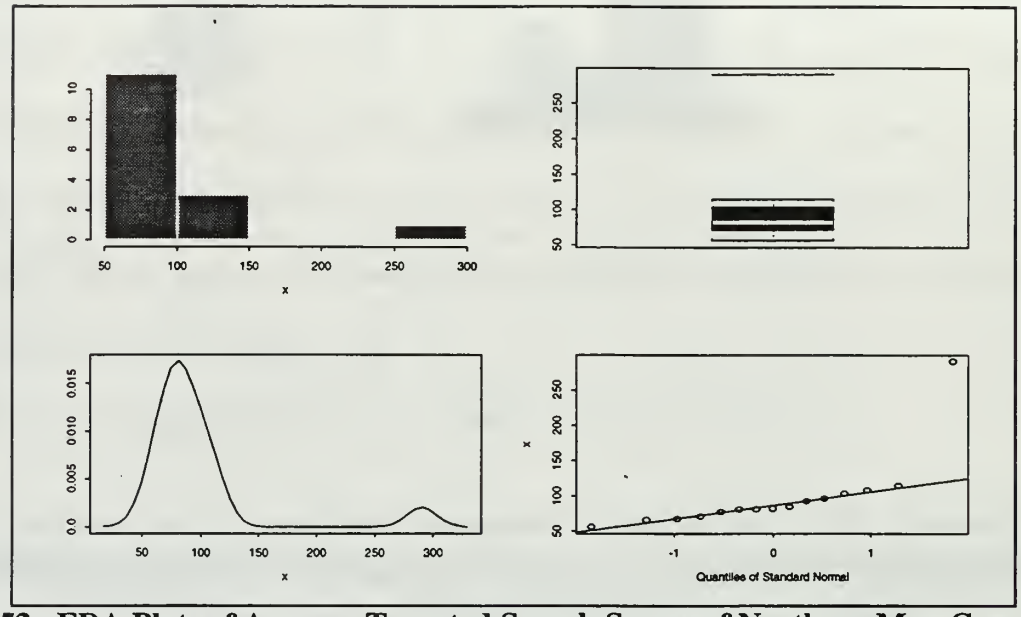


Figure 53. EDA Plots of Average Targeted Search Scores of North-up Map Group in UVE

PRIMED SEARCH			
Participant No	RED	GREEN	BLUE
1	187	99	78
2	78	141	42
3	59	74	57
4	55	24	24
5	41	34	62
6	324	126	128
7	53	46	42
8	333	30	87
9	59	34	37
10	99	38	64
11	46	60	67
12	79	27	41
13	155	49	96
14	130	43	44
15	46	36	43
Average	**116.26**	**57.4**	**60.8**
Std.dev.	**96.29**	**36.68**	**27.28**

Table 20: Primed Search Scores of North-up Map Group in UVE

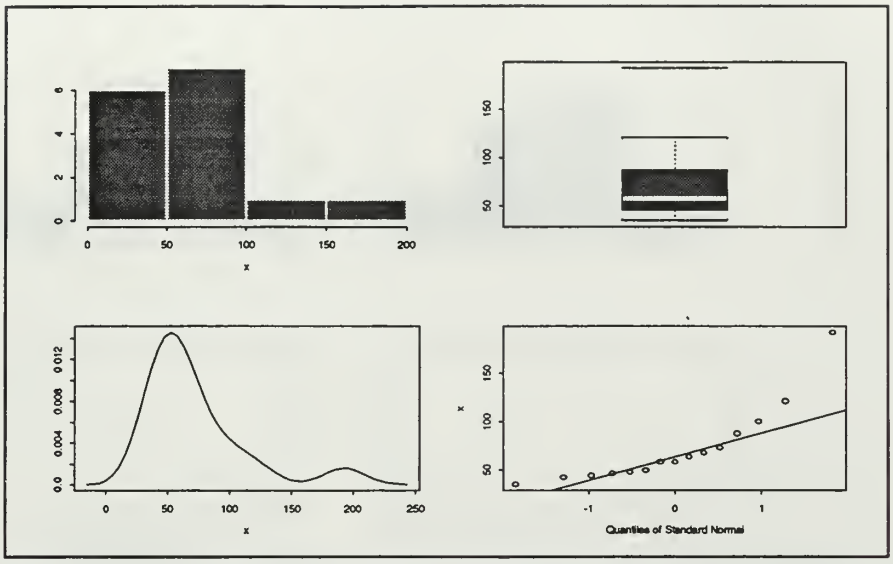


Figure 54. EDA Plots of Average Primed Search Scores of North-up Map Group in UVE

NAÏVE	SEARCH
Participant No	YELLOW
1	116
2	122
3	129
4	85
5	29
6	82
7	55
8	144
9	199
10	85
11	67
12	XXXXXXX
13	51
14	133
15	193
Average	**106.42**
Std.dev.	**50.99**

Table 21: Naive Search Scores of North-up Map Group in UVE

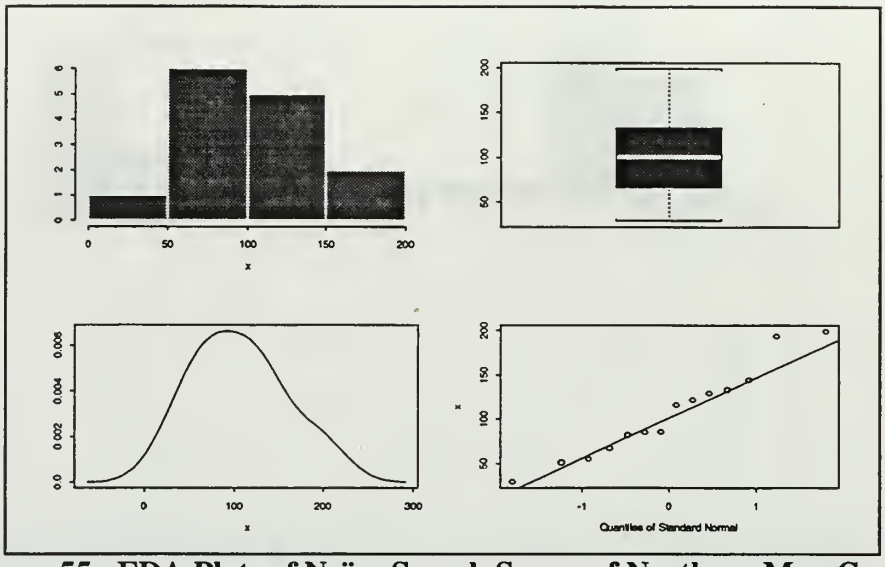


Figure 55. EDA Plots of Naïve Search Scores of North-up Map Group in UVE

D. NORTH-UP MAP GROUP OPEN OCEAN VIRTUAL ENVIRONMENT (OOVE) TARGETED, PRIMED, AND NAÏVE SEARCH RESULTS

TARGETE D SEARCH			
Participant No	RED	GREEN	BLUE
1	84	71	125
2	69	80	120
3	78	96	122
4	64	62	95
5	95	68	130
6	116	65	233
7	85	66	104
8	135	81	140
9	74	50	133
10	95	96	181
11	76	59	108
12	96	70	127
13	106	73	118
14	82	98	151
15	77	85	108
Average	88.8	74.67	133
Std.dev.	18.95	14.38	34.68

Table 22: Targeted Search Results of North-up Map Group in OOVE

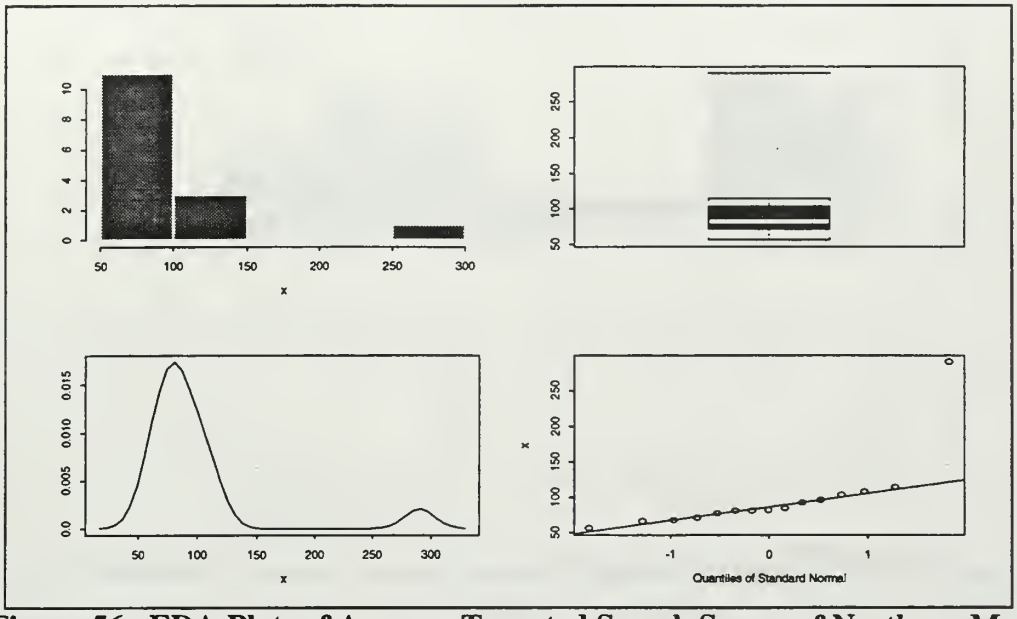


Figure 56. EDA Plots of Average Targeted Search Scores of North-up Map Group in OOVE

PRIMED SEARCH			
Participant No	RED	GREEN	BLUE
1	135	61	99
2	159	59	103
3	165	63	116
4	148	59	113
5	88	71	142
6	181	72	137
7	100	78	82
8	144	65	105
9	132	87	80
10	128	61	116
11	113	47	119
12	121	94	82
13	151	49	101
14	239	55	86
15	103	38	106
Average	140.47	63.93	105.8
Std.dev.	37.48	14.83	18.87

Table 23: Primed Search Scores of North-up Map Group in OOVE

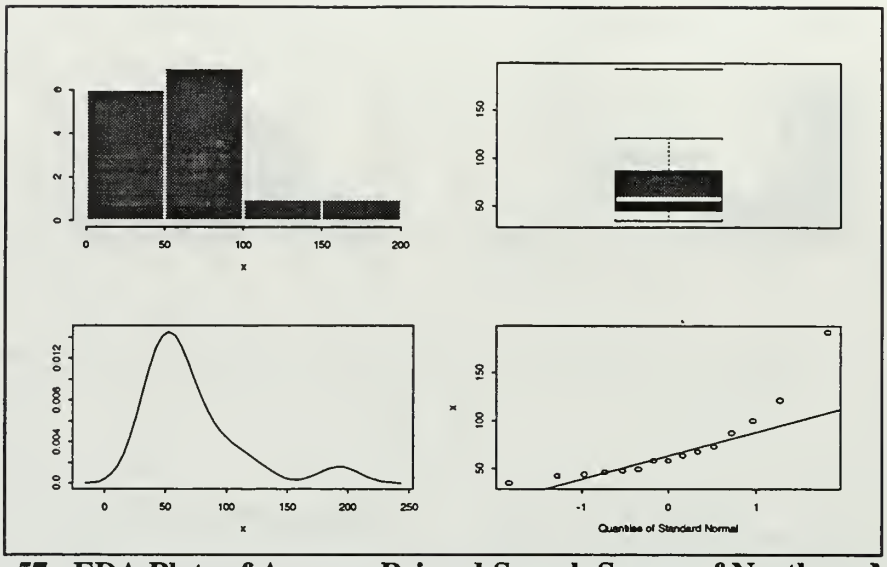


Figure 57. EDA Plots of Average Primed Search Scores of North-up Map Group in OOVE

NAÏVE	SEARCH
Participant No	YELLOW
1	255
2	926
3	451
4	263
5	557
6	345
7	305
8	296
9	216
10	1090
11	638
12	337
13	371
14	1007
15	411
Average	497.87
Std.dev.	288.21

Table 24: Naïve Search Scores of North-up Map Group in OOVE

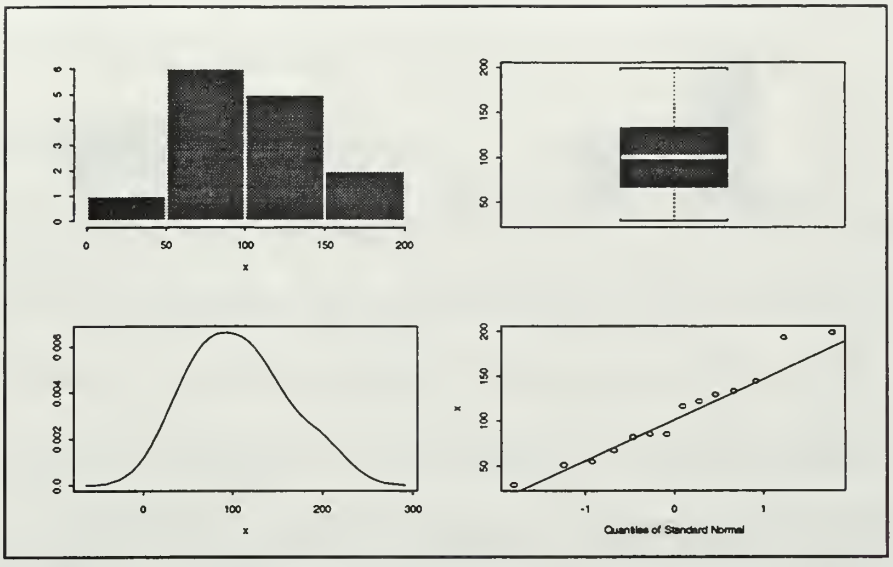


Figure 58. EDA Plots of Naïve Search Scores of North-up Map Group in OOVE

E. SELF-ABILITY EVALUATION (SAE) AND SANTA BARBARA SENSE-OF-DIRECTION SCALE (SBSODS) RESULTS OF FORWARD-UP MAP GROUP

For the forward-up map group, no participants evaluated themselves as beginners with low navigation ability, 10 participants evaluated themselves as intermediate with medium navigation ability, and five participants evaluated themselves as experts with high navigation ability out of total fifteen participants (Table 25).

Participant No	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Avg	Std. Dev.
SBSODS Score	2.2	2.0	2.2	4.13	3.13	3.26	2.2	2.53	2.6	2.93	3.6	3.4	2.66	1.93	2.6	2.76	0.64
SAE	med	med	med	med	med	high	high	high	med	med	med	med	med	high	high		

Table 25: SBSODS and SAE scores of Forward-up map group

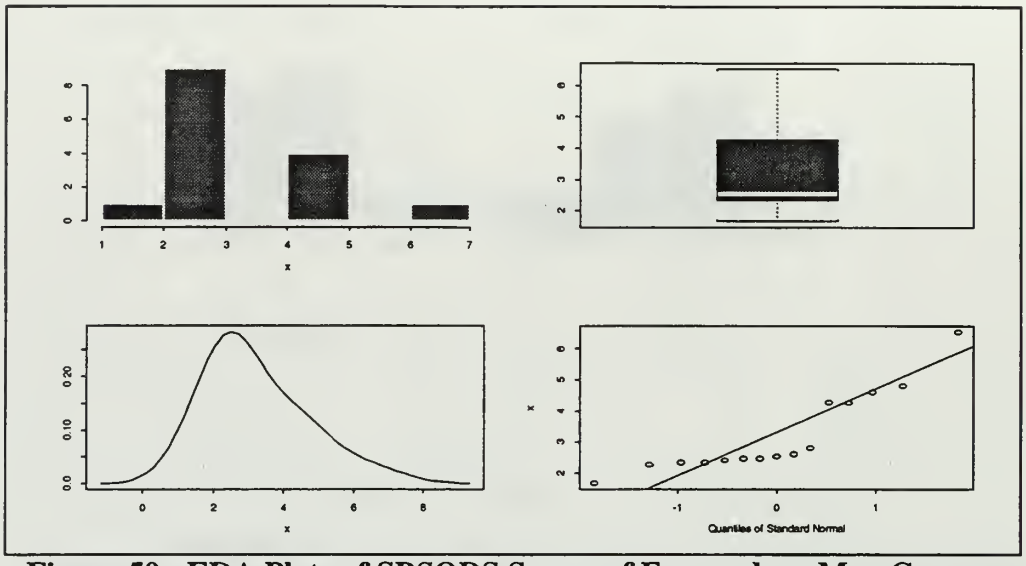


Figure 59. EDA Plots of SBSODS Scores of Forward-up Map Group

The Santa Barbara Sense-of-Direction Scale was described previously. For the participants of forward-up map group, the mean score was 2.76 with a standard deviation of 0.64 (Figure 59; Table 25).

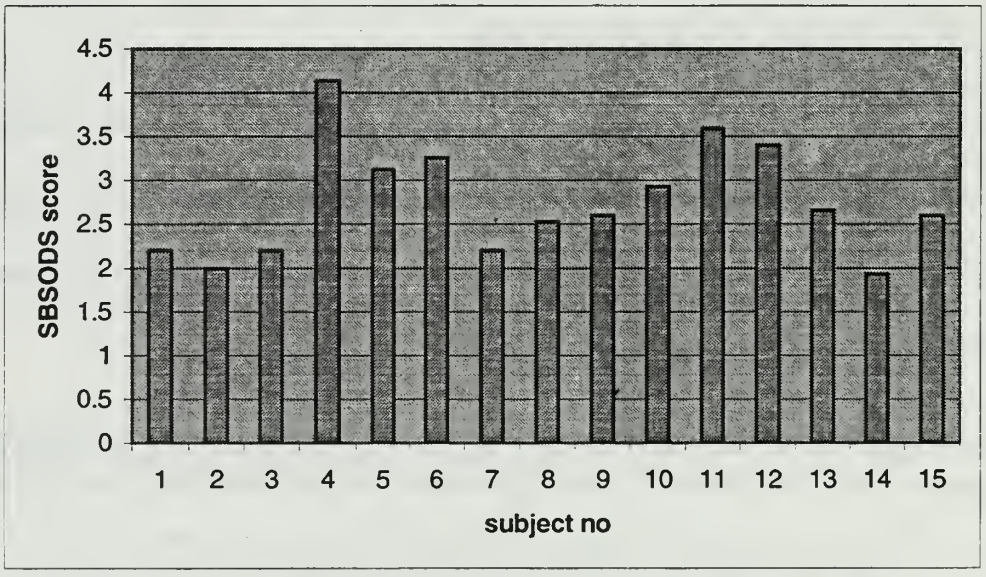


Figure 60. Graphical Representation of SBSODS Scores of Forward-up Map Group

F. GUILFORD-ZIMMERMAN SPATIAL VISUALIZATION (SV) AND SPATIAL ORIENTATION (SO) RESULTS OF FORWARD-UP MAP GROUP

Before giving the Spatial Visualization test to the participants, all of them were given unlimited time for examining the example questions and given explanations to any questions they had. Each participant was given a 10-minute period for the test after the participant indicated that he/she was ready. Scores were calculated according to the following formula as instructed in **Guilford-Zimmerman Manual of Instructions and Interpretations** (Figure 62, Table 26).

Score = Number of right answers - (number of wrong answers / 4)

The genders and the backgrounds of each participant are shown in figure 61.

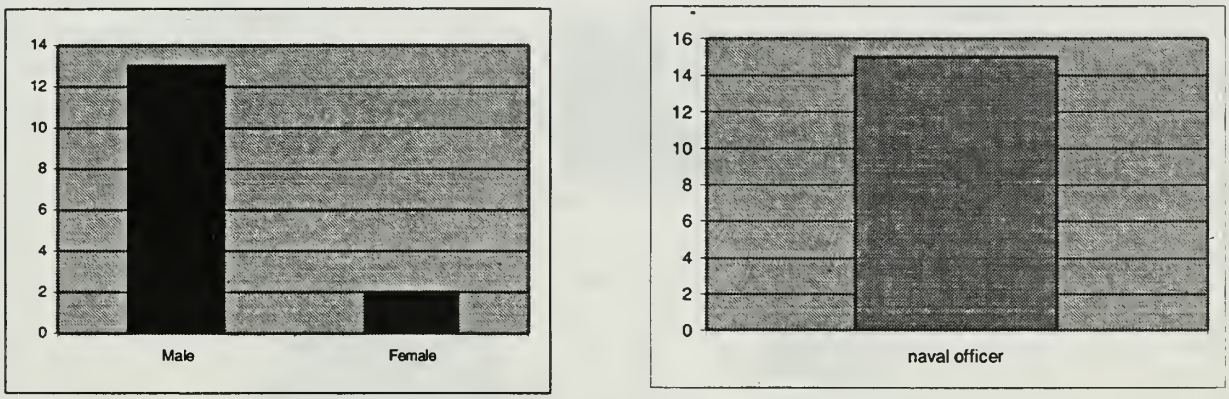


Figure 61. Gender and Background of Participants of Forward-up Map Group

SPATIAL VISUALIZATION TEST SCORES			
Participant No	Right No	Wrong No	Score
16	26	8	24.00
17	23	3	22.25
18	14	20	9.00
19	23	5	21.75
20	28	0	28.00
21	20	10	17.50
22	17	3	16.25
23	7	13	3.75
24	27	2	26.50
25	15	6	13.50
26	15	6	13.50
27	25	5	23.75
28	15	6	13.50
29	20	4	19.00
30	21	4	20.00
Average	**19.73**	**6.33**	**18.15**
Std.dev.	**5.86**	**4.95**	**6.69**

Table 26. Spatial Visualization Scores of Forward-up Map Group

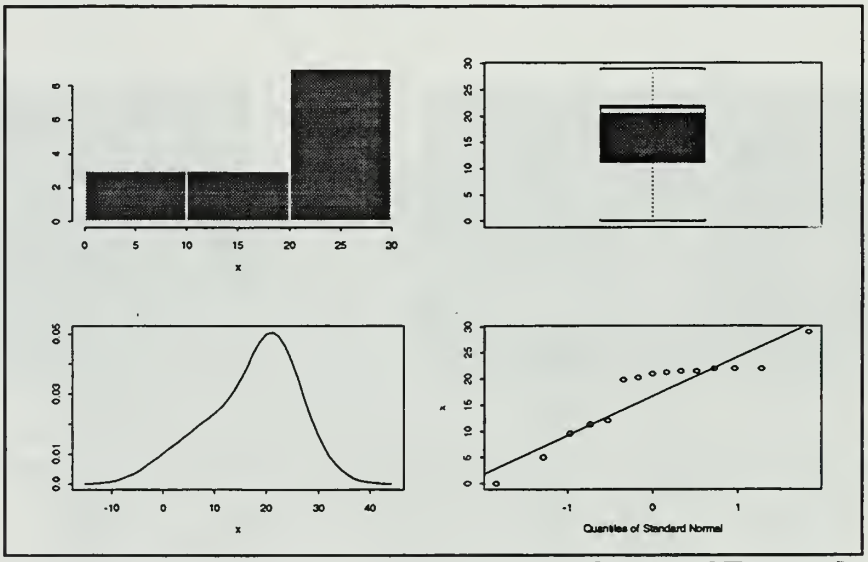


Figure 62. EDA Plots of Spatial Visualization Test Scores of Forward-up Map Group

Before giving the Spatial Orientation test to the participants, all of them were given limitless time for examining the example questions and given explanations to any questions they had. Each participant was given a 10-minute period for the test after the

participant indicated that he/she was ready. Scores were calculated according to the following formula as advised in **Guilford-Zimmerman Manual of Instructions and Interpretations** (Figure 63, Table 27).

Score = Number of right answers - (number of wrong answers / 4)

SPATIAL ORIENTATION TEST SCORES			
Participant No	Right No	Wrong No	Score
16	23	16	19.00
17	21	9	18.75
18	35	1	34.75
19	29	1	28.75
20	31	7	29.25
21	23	8	21.00
22	20	4	19.00
23	16	8	14.00
24	31	2	30.50
25	25	2	24.50
26	19	17	14.75
27	21	6	19.50
28	25	2	24.50
29	25	3	24.25
30	26	4	25.00
Average	**24.67**	**6.00**	**23.17**
Std.dev.	**5.14**	**5.03**	**5.92**

Table 27: Spatial Orientation Scores of Forward-up Map Group

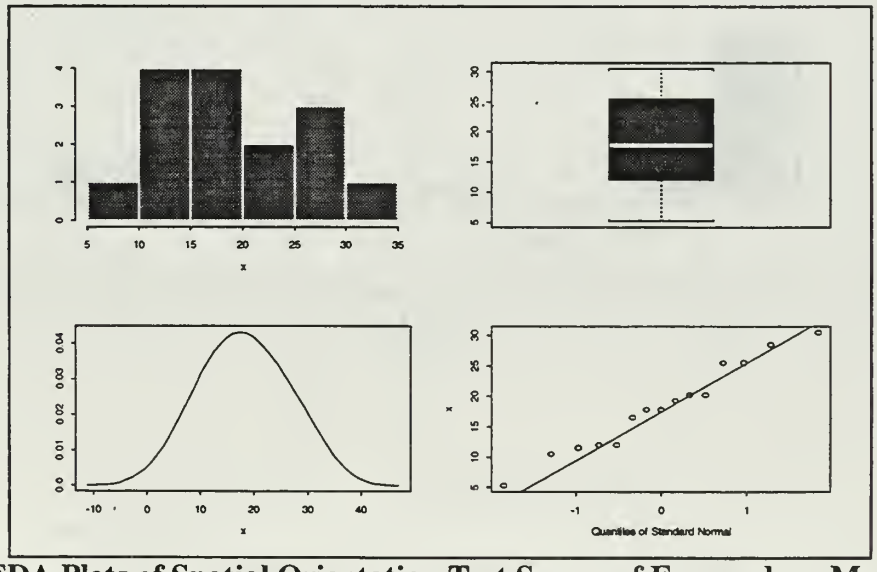


Figure 63. EDA Plots of Spatial Orientation Test Scores of Forward-up Map Group

G. FORWARD-UP MAP GROUP URBAN VIRTUAL ENVIRONMENT (UVE) TARGETED, PRIMED, AND NAÏVE SEARCH RESULTS

TARGETE D SEARCH			
Participant No	RED	GREEN	BLUE
16	129	45	38
17	56	37	41
18	128	35	46
19	49	35	55
20	41	31	24
21	259	73	85
22	80	59	63
23	215	90	89
24	118	44	87
25	195	71	75
26	63	28	22
27	73	38	48
28	206	55	46
29	108	36	43
30	100	55	21
Average	**121.33**	**48.80**	**52.20**
Std.dev.	**67.86**	**18.02**	**23.10**

Table 28: Targeted Search Scores of Forward-up Map Group in UVE

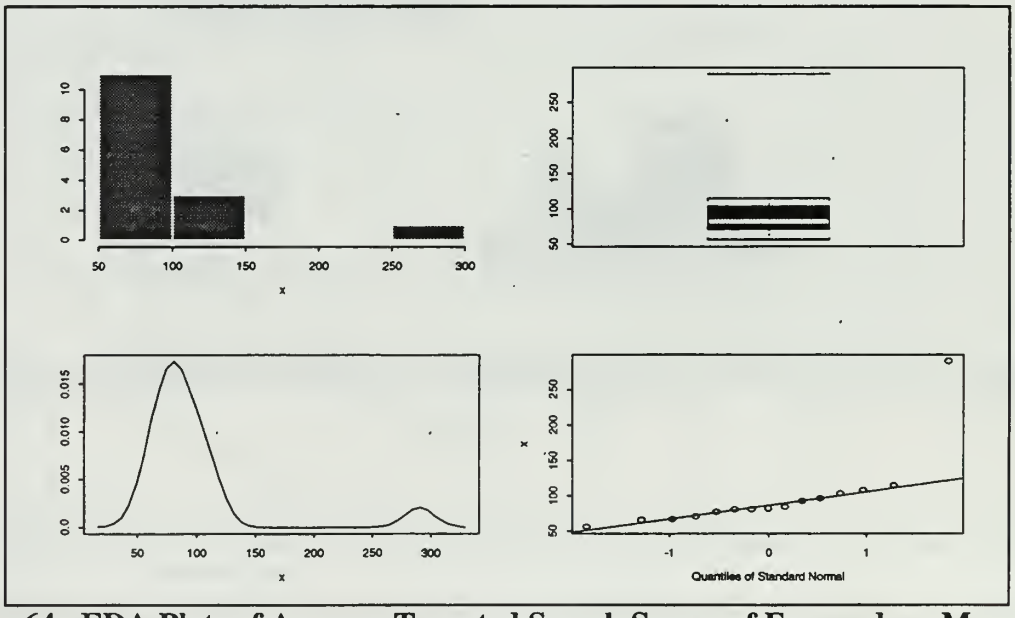


Figure 64. EDA Plots of Average Targeted Search Scores of Forward-up Map Group in UVE

PRIMED SEARCH			
Participant No	RED	GREEN	BLUE
16	41	37	113
17	502	220	74
18	42	48	40
19	46	37	41
20	20	19	17
21	502	211	70
22	502	40	62
23	460	252	51
24	85	107	62
25	502	67	61
26	55	26	25
27	60	42	44
28	502	82	48
29	31	26	24
30	71	25	26
Average	**228.07**	**82.60**	**50.53**
Std.dev.	**226.23**	**79.05**	**24.69**

Table 29: Primed Search Scores of Forward-up Map Group in UVE

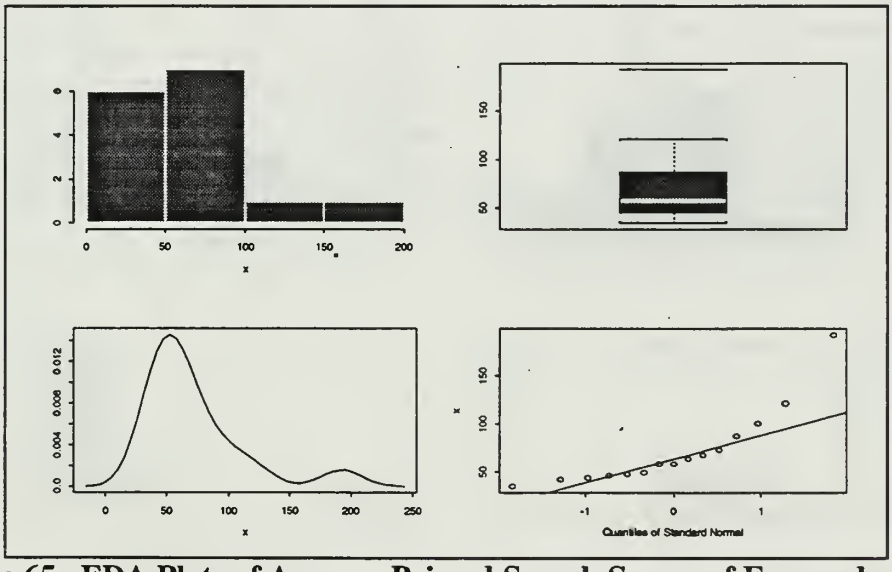


Figure 65. EDA Plots of Average Primed Search Scores of Forward-up Map Group in UVE

NAÏVE	SEARCH
Participant No	YELLOW
16	120
17	148
18	144
19	48
20	59
21	438
22	65
23	146
24	90
25	166
26	185
27	186
28	249
29	81
30	92
Average	147.80
Std.dev.	97.85

Table 30: Naive Search Scores of Forward-up Map Group in UVE

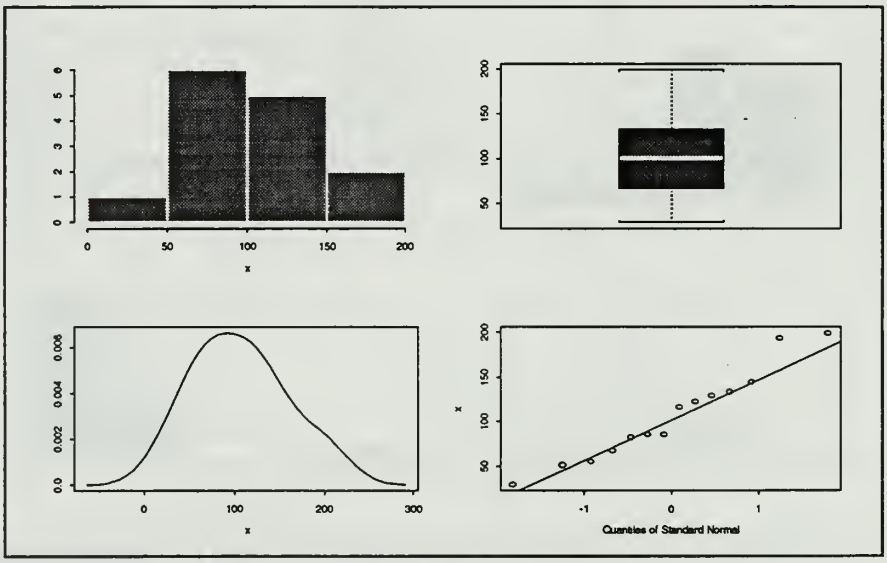


Figure 66. EDA Plots of Naive Search Scores of Forward-up Map Group in UVE

H. FORWARD-UP MAP GROUP OPEN OCEAN VIRTUAL ENVIRONMENT (OOVE) TARGETED, PRIMED, AND NAÏVE SEARCH RESULTS

TARGETE D SEARCH			
Participant No	**RED**	**GREEN**	**BLUE**
16	65	30	62
17	62	92	138
18	105	75	92
19	130	61	59
20	59	51	79
21	121	155	174
22	87	88	137
23	150	75	117
24	80	71	113
25	111	77	139
26	69	57	54
27	58	42	97
28	89	62	122
29	62	81	143
30	88	80	104
Average	89.07	73.13	108.67
Std.dev.	28.72	28.37	35.10

Table 31: Targeted Search Scores of Forward-up Map Group in OOVE

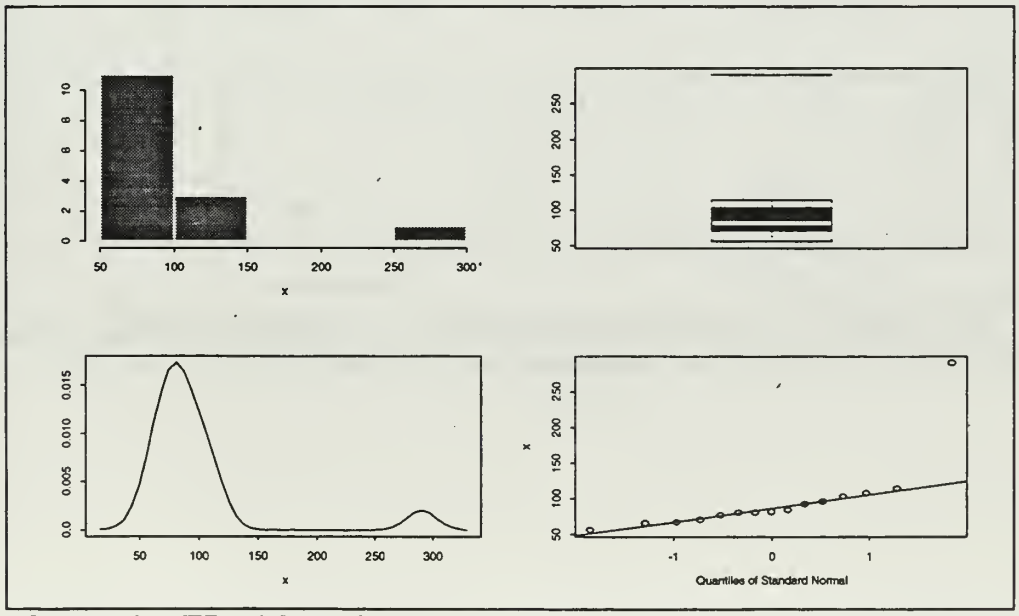


Figure 67. EDA Plots of Average Targeted Search Scores of Forward-up Map Group in OOVE

PRIMED SEARCH			
Participant No	RED	GREEN	BLUE
16	146	43	71
17	104	70	98
18	113	52	127
19	103	169	88
20	50	56	74
21	102	64	127
22	183	82	95
23	184	69	108
24	94	72	75
25	133	208	135
26	59	46	88
27	179	51	76
28	183	53	160
29	88	44	102
30	90	23	50
Average	120.73	73.47	98.27
Std.dev.	45.11	49.43	29.08

Table 32: Primed Search Scores of Forward-up Map Group in OOVE

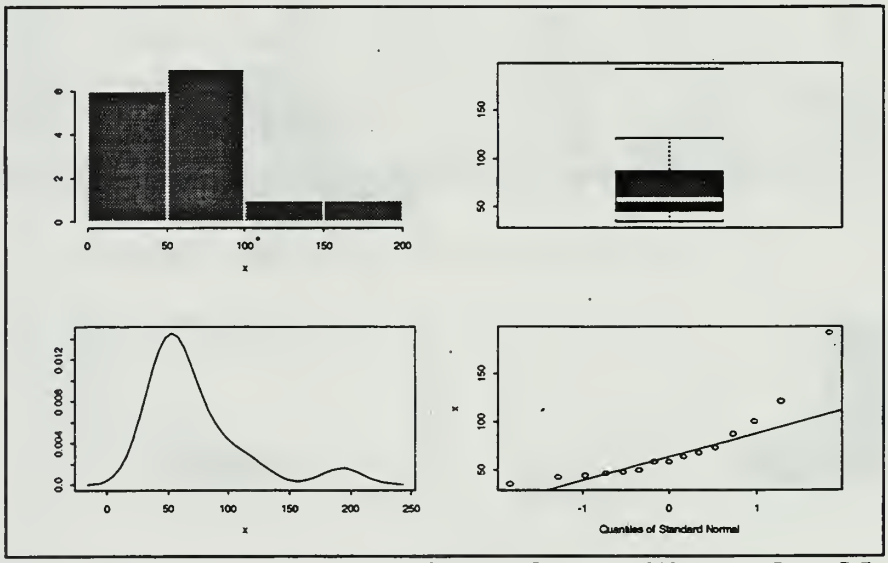


Figure 68. EDA Plots of Average Primed Search Scores of Forward-up Map Group in OOVE

NAÏVE	SEARCH
Participant No	YELLOW
16	237
17	276
18	598
19	572
20	343
21	655
22	489
23	552
24	600
25	297
26	200
27	440
28	527
29	303
30	318
Average	427.13
Std.dev.	152.00

Table 33: Naïve Search Scores of Forward-up Map Group in OOVE

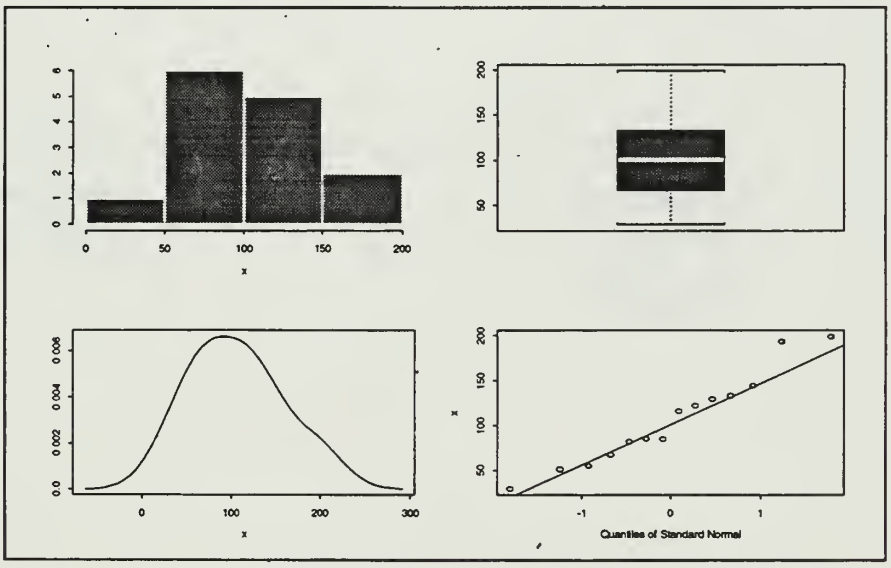
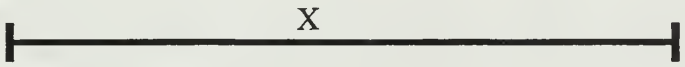


Figure 69. EDA Plots of Naïve Search Scores of Forward-up Map Group in OOVE

APPENDIX B: SELF ABILITY EVALUATION TEST

Participant ID:_____

The following bar line depicts the navigation ability evaluation of an average infantry officer with five years experience. The "X" indicates his ability level.



Knows how to read a map

Navigates with no errors; Rarely looks at map

Place an "X" on the line below were you feel your navigational abilities are at this time.

Knows how to read a map

Navigates with no errors; Rarely looks at map

APPENDIX C: SANTA BARBARA SENSE-OF-DIRECTION SCALE TEST

Participant ID: _____ Date: _____ SEX: F M AGE:____

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experience. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for were I left things.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W)

   strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

    strongly agree 1 2 3 4 5 6 7 strongly disagree

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